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## Translation of JP 2004-67413 A

## [Title of the Invention]

5 CATALYST SUPPORT SUBSTRATE, GROWTH METHOD OF CARBON NANOTUBE USING THE SAME, AND TRANSISTOR USING CARBON NANOTUBE

## [Claim(s)]

## 10 [Claim 1]

A catalyst support substrate used for the vapor growth of a carbon nanotube characterized by comprising: a principal surface including

(a) a first field including a carbon nanotube vapor growth catalyst, and

15 (b) a second field including a metal containing at least one element selected from group 2 to 14 of periodic-table, or its compound (however, the matter chosen as the carbon nanotube vapor growth catalyst in the first field is excluded).

## [Claim 2]

20 The catalyst support substrate according to claim 1, characterized by that the carbon nanotube is a monolayer carbon nanotube.

## [Claim 3]

The catalyst support substrate according to claim 1 or 2, characterized by that the carbon nanotube vapor growth catalyst includes a metal or compound containing at least one selected from group consisting of Fe, Ni, Co, Ru, Rh, Pd, Os, Ir, Pt, La, Y, Mo, and Mn.

## [Claim 4]

30 The catalyst support substrate according to one of claims 1 to 3, characterized by that the metal or compound constituting the second field contains at least one element selecting from group consisting of Al, Mo, Ti, Ta, Cr, Cu, Mn, Mg, Zr, Hf, W, Ru, Rh, Zn, and Sn.

## [Claim 5]

35 The catalyst support substrate according to one of claims 1 to 4, characterized by that a catalyst support film containing the second field and a catalyst film containing the first field and covering a part of the catalyst support film are formed in this order on the principal surface of the catalyst support substrate.

2004-67413A**[Claim 6]**

The catalyst support substrate according to claim 5 characterized by that the catalyst film is a film formed by vacuum deposition, sputtering method, or CVD method.

5 **[Claim 7]**

The catalyst support substrate according to claim 5 or 6 characterized by that the catalyst support film contains a metal film containing at least one element selected from group 2 to 14 of periodic-table and a film obtained by oxidizing or hydroxylating an upper part of the 10 metal film.

## [Claim 8]

The catalyst support substrate according to one of claims 5 to 7 characterized by that a surface of the catalyst support film contains at least one selecting from aluminum natural oxidation film, boehmite, alpha 15 alumina, gamma alumina, delta alumina, and theta alumina.

## [Claim 9]

A transistor characterized by comprising:  
a substrate,  
a catalyst-containing film formed on the principal surface of the 20 substrate,  
a carbon nanotube elongated from the catalyst-containing film to a horizontal direction of the substrate,  
a first electrode linked to a part of the carbon nanotube by the side of the catalyst-containing film,  
a second electrode linked to a part of the carbon nanotube by the other side, and  
a gate electrode that applies voltage to the carbon nanotube.

## [Claim 10]

The transistor according to claim 9, characterized by that the carbon 30 nanotube is a monolayer carbon nanotube.

## [Claim 11]

The transistor according to claim 9 or 10, characterized by that the gate electrode is formed in upper part of the carbon nanotube.

## 35 [Claim 12]

The transistor according to one of claims 9 to 11, characterized by that the gate electrode is formed on a rear surface of the substrate.

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## [Claim 13]

The transistor according to one of claims 9 to 12, characterized by that the second electrode is formed so as to be away from the first electrode and to surround the first electrode.

## 5 [Claim 14]

The transistor according to one of claims 9 to 13, characterized by that the catalyst-containing film contains a surface including

(a) a first field including a carbon nanotube vapor growth catalyst, and

10 (b) a second field including a metal containing at least one element selected from group 2 to 14 of periodic-table, or its compound (however, the matter chosen as the carbon nanotube vapor growth catalyst in the first field is excluded).

## [Claim 15]

15 The transistor according to one of claims 9 to 14, characterized by that the metal or compound constituting the second field contains at least one element selecting from group consisting of Al, Mo, Ti, Ta, Cr, Cu, Mn, Mg, Zr, Hf, W, Ru, Rh, Zn, and Sn.

## [Claim 16]

20 The transistor according to one of claims 9 to 15, characterized by that the carbon nanotube vapor growth catalyst includes a metal or compound containing at least one selected from group consisting of Fe, Ni, Co, Ru, Rh, Pd, Os, Ir, Pt, La, Y, Mo, and Mn.

## [Claim 17]

25 The transistor according to one of claims 9 to 16, characterized by that the catalyst-containing film contains a catalyst support film containing the second field and a catalyst film containing the first field and covering a part of the catalyst support film.

## [Claim 18]

30 The transistor according to one of claim 17, characterized by that the catalyst support film contains a metal film containing at least one element selected from group 2 to 14 of periodic-table and the film obtained by oxidizing or hydroxylating an upper part of the metal film.

## [Claim 19]

35 A growth method of a carbon nanotube characterized by growing up the carbon nanotube by supplying a material gas containing carbon to the catalyst support substrate according to one of claims 1 to 8.

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## [Claim 20]

The growth method of a carbon nanotube according to claim 19, characterized by that the carbon nanotube is a monolayer carbon nanotube.

## [Claim 21]

5 The growth method of a carbon nanotube according to claim 19 or 20, characterized by growing up the carbon nanotube to a horizontal direction in a plane of the catalyst support substrate.

## [Claim 22]

10 The growth method of a carbon nanotube according to one of claims 19 to 21, characterized by achieving an orientation of the carbon nanotube by applying an electric field to the catalyst support substrate during the step of growing up the carbon nanotube.

## [Claim 23]

15 The growth method of a carbon nanotube according to one of claims 19 to 22, characterized by further comprising:

a step of bringing a reducing gas into contact with surface of the catalyst support substrate, and then

achieving the step of growing up the carbon nanotube.

## [Claim 24]

20 A growth method of a carbon nanotube, characterized by comprising steps of:

forming a catalyst-containing film with predetermined pattern on a substrate, and then

25 growing up a carbon nanotube to a substrate horizontal direction by supplying carbon material containing gas.

## [Claim 25]

The growth method of a carbon nanotube according to claim 24, characterized by that the carbon nanotube is a monolayer carbon nanotube.

## [Claim 26]

30 The growth method of a carbon nanotube according to claim 24 or 25, characterized by that the catalyst-containing film contains a surface including

(a) a first field including a carbon nanotube vapor growth catalyst, and

35 (b) a second field including a metal containing at least one element selected from group 2 to 14 of periodic-table, or its compound (however, the matter chosen as the carbon nanotube vapor growth catalyst in the first

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field is excluded).

[Claim 27]

The growth method of a carbon nanotube according to one of claims 24 to 26, characterized by that the carbon nanotube vapor growth catalyst includes a metal or compound containing at least one selected from group consisting of Fe, Ni, Co, Ru, Rh, Pd, Os, Ir, Pt, La, Y, Mo, and Mn.

[Claim 28]

The growth method of a carbon nanotube according to one of claims 24 to 27, characterized by that the metal or compound constituting the second field contains at least one element selecting from group consisting of Al, Mo, Ti, Ta, Cr, Cu, Mn, Mg, Zr, Hf, W, Ru, Rh, Zn, and Sn.

[Claim 29]

The growth method of a carbon nanotube according to one of claims 24 to 28, characterized by that the step of forming the catalyst-containing film includes steps of:

forming a catalyst supporting film with predetermined pattern on a substrate, and

forming a catalyst film covering a part of the catalyst supporting film.

[Claim 30]

The growth method of a carbon nanotube according to claim 29, characterized by that the step of forming the catalyst supporting film includes steps of:

forming a metal film containing at least one element selected from group 2 to 14 of periodic-table, and

forming the catalyst supporting film by oxidizing or hydroxylating an upper part of the metal film.

[Claim 31]

The growth method of a carbon nanotube according to claim 29 or 30, characterized by that the catalyst film is formed by vacuum deposition, sputtering method, or CVD method.

[Claim 32]

The growth method of a carbon nanotube according to one of claims 24 to 31, characterized by that the carbon nanotube is oriented by applying a electric field to the substrate during the step of growing up the carbon nanotube.

[Claim 33]

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The growth method of a carbon nanotube according to one of claims 24 to 32, characterized by further comprising steps of:

bringing a reducing gas into contact with surface of the catalyst support substrate, and then

5 achieving the step of growing up the carbon nanotube.

[Claim 34]

A method for producing a transistor characterized by comprising steps of:

10 forming a carbon nanotube elongated to a horizontal direction of a substrate according to the growth method of one of claims 24 to 33,

forming a first electrode connected to a catalyst containing film side portion of the carbon nanotube and forming a second electrode connected to another side portion of the carbon nanotube, and

forming a gate electrode applying a voltage to the carbon nanotube.

2004-67413A**[Detailed Description of the Invention]****[0001]****[Field of the Invention]**

The invention relates to a catalyst support substrate used for growing up a carbon nanotube on a substrate, and method for growing up a carbon nanotube, and device such as a transistor using a carbon nanotube.

**[0002]****[Description of the Prior Art]**

As a manufacture method of a high quality monolayer carbon nanotube, a chemical-vapor-deposition reaction (CVD) is hopeful. It is because it has possibility that growth of a monolayer carbon nanotube will be controllable by controlling a catalyst.

**[0003]**

Generally, catalyst metals, such as iron, cobalt and nickel, are required in addition to a carbon material for manufacture of a monolayer carbon nanotube. The manufacture method of the monolayer carbon nanotube by the conventional vapor growth, nano particle (very fine particle) of metallic oxides, such as an alumina and a silica or materials having holes such as zeolite was used as support of a catalyst. Such support is melted to a solvent together with salts of iron etc. used as a catalyst, and a catalyst solution is prepared, and the catalyst solution is applied on a substrate, and is dried, and thus, the catalyst for forming monolayer carbon nanotube is obtained.

**[0004]**

An example which uses iron nitrate and 9 hydrate ( $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ ) and molybdenil acetylacetone ( $\text{Mo}(\text{acac})_2$ ) as a catalyst salt, and the catalyst solution that uses alumina nano particle as support, and synthesizes a monolayer carbon nanotube by using methane as a carbon source is indicated by the 395th volume, page 878 of Nature (1998).

Moreover, an example which uses a catalyst solution including alumina nano particle, iron, and Mo salt as support and a catalyst respectively, carries out CVD growth of a monolayer carbon nanotube by using CO as a carbon source is disclosed in the 296th volume, page 195 of Chemical Physics Letter (1998).

**[0005]**

However, it was difficult to grow up a monolayer carbon nanotube selectively by the above-mentioned method which uses the catalyst solution.

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In order to form a catalyst in a predetermined pattern, the method of using a mask of a resist having predetermined opening is adopted, and the following two methods are usually considered.

[0006]

5 A primary method is a method so-called lift-off method. After forming a resist all over a silicon substrate, the resist at a location where a carbon nanotube is grown up is removed, and a catalyst solution is applied to the whole substrate surface, and it is dried. Then, the substrate is immersed in the solvent of a resist, and catalyst on the resist is removed  
10 with the resist. The method is generally used to patterning of a metal thin film.

[0007]

15 In the second method, firstly, a catalyst solution is applied to all over a substrate and dried, and a resist is applied on it and patterning is performed. In this case, the resist at a part where a carbon nanotube is grown up is not removed. Then, the catalyst of the part where is not covered with the resist is removed by a certain method.

[0008]

20 However, a primary method required that the solution which did not melt a resist needed to be used for the solvent of a catalyst solution. Moreover, it was very difficult to have made the catalyst of desired thickness adhere to a part not including the resist of the resist pattern. Nature 395th volume 878 pages (1998) actually discloses a example in which the nano particle of alumina, iron nitrate and 9 hydrate  
25 ( $\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$ ), and molybdenil acetylacetoneato ( $\text{Mo}(\text{acac})_2$ ) are dissolved in a methanol and a polymethylmethacrylate (PMMA) resist is patterned. In this method, the edge of the patterned catalyst is ambiguous, and the pattern configuration of a catalyst is not reflecting the pattern of a resist. This also shows that the technique of using nano particle has a technical  
30 problem in the controllability of pattern formation.

[0009]

Moreover, when the second method is adopted, dry etching or wet etching can be considered as an method of removing the catalyst and support of a part where a carbon nanotube is not synthesized. But since  
35 the etching-proof property of a resist is lower than iron and alumina, it is difficult to hold the pattern configuration of a resist at present.

[0010]

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Furthermore, in the above-mentioned first and the second method, in addition to the above-mentioned technical problem, the adhesion between the catalyst support film and a substrate was not enough, and it had the technical problem that exfoliation was easy to occur.

## 5 [0011]

As an method of solving the trouble of the method using such a solution, a method is well-known in which a catalyst film is formed according to dry processes (such as vacuum deposition) on a substrate, and a carbon nanotube is grown up from the catalyst film. Hereafter, a 10 conventional technique which forms a catalyst thin film according to a dry process is explained.

## [0012]

JP2001-20072A is related with a method in which large quantity of the high grade carbon nanotube which aligned vertically at the low 15 temperature below the deformation temperature of a large area substrate is synthesized. The bulletin discloses a method in which a catalyst metal film is formed on a substrate, and catalyst metal particles of the nano size are formed by etching the catalyst metal film, and carbon nanotubes which aligned on the substrate are formed using thermo chemical vapor deposition. 20 The bulletin discloses that, in the lower part of a catalyst metal film, insulating layer (such as silicon oxide film or alumina film) may be formed in order to prevent a formation of silicide film by the reaction between the catalyst metal film and a substrate.

## [0013]

Moreover, JP2001-115070A and JP2001-115071A disclose a technique 25 in which a thin film of "non-catalyst metals, such as nickel and Cu," is formed as a base layer, and catalyst metal thin film (such as Fe and Co) is formed on it at a predetermined pattern, and a graphite nano fiber is grown up on the thin film pattern. The bulletin discloses that alloying takes 30 place between the catalyst metal thin film and the non-catalyst metal and the adhesion between both thin films improves, and adhesion between the base layer and the substrate also improves. Moreover, JP2001-115071A discloses a structure in which a thin film pattern of Fe is formed on nickel thin film, and a carbon nanotube is formed only on the Fe pattern.

## 35 [0014]

However, it was not easy to obtain high yield by the technique disclosed in the above-mentioned bulletin. Inventor of this invention

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disclosed recently that when an iron thin film was vapor-deposited on a sapphire single crystal substrate, a monolayer carbon nanotube could grow up (Chemical Physics Letters (2002) contribution). This shows that growth of a monolayer carbon nanotube is influenced with the matter which  
5 supports a catalyst, and shows that the synergism of support and a catalyst metal is important. However, the technique disclosed in above-mentioned bulletin is not designing the base layer which supports a catalyst from a viewpoint of the yield of such a carbon nanotube, and has prepared the base layer, from a viewpoint of prevention of a silicide reaction (JP2001-20072A),  
10 or a viewpoint of the improvement of the adhesion between a catalyst metal and a substrate (JP2001-115070A and JP2001-115071A). Therefore, the conventional technique should be improved about the point of growing up a carbon nanotube with high yield.

[0015]

15 Moreover, each technique disclosed in above-mentioned bulletin was that for the application to a field emission mold display etc., and a multilayer carbon nanotube is grown up into a substrate perpendicular direction, and is going to apply this to the device. Therefore, it does not give useful knowledge to the technique of applying the carbon nanotube  
20 horizontally grown up to the substrate to the device, especially the technique of using a monolayer carbon nanotube.

[0016]

25 On the other hand, research about a transistor using a monolayer carbon nanotube is active. A transistor of a top gate type which uses the monolayer carbon nanotube is disclosed in APPLIED PHYSICS LETTERS VOLUME 80, NUMBER 20, and 20 MAY 2002.

[0017]

30 The transistor has a source electrode, a drain electrode and a monolayer carbon nanotube arranged between these electrodes, and has a configuration in which the gate electrode is formed on the carbon nanotube.

[0018]

35 The transistor is produced through the following steps. Firstly, silicon oxide is formed on a silicon substrate, and a carbon nanotube is distributed on it (it is distributed in a solution and is spin-coated). Subsequently, the location of a carbon nanotube is decided using the probe of AFM (atomic force microscope). Then, a source electrode and a drain electrode are formed by electron beam lithography (the lift-off method).

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The constituent insulating layer of a source drain electrode uses titanium. TiC is formed by annealing after source drain electrodes formation. Thereby, the adhesion of a source drain electrode and a carbon nanotube improves. Then, an insulating layer is formed on the source electrode, the 5 drain electrode and the carbon nanotube, and a gate electrode is further formed on it. The transistor using a carbon nanotube is thus produced.  
[0019]

However, it was difficult to maintain stably the contact resistance between a source drain electrode and a carbon nanotube to low resistance 10 with this transistor. In the above-mentioned conventional technique, that problem is improved by using titanium as an electrode material in order to alloy a carbon nanotube and titanium. But in order to realize the transistor in which high-speed operation, still lower contact resistance is desired. Moreover, in the above-mentioned conventional technique, since a 15 complicated process was needed for positioning a carbon nanotube, it also needed an improvement at the point of the yield.

[0020]

**[Problem(s) to be Solved by the Invention]**

This invention is made in view of the above-mentioned situation.  
The object of this invention is to improve the adhesion of a catalyst-containing film and a substrate and the patterning property, and is to form 20 stably, on a substrate surface, a carbon nanotube that is patterned to a designed pattern. Moreover, another object of this invention is to offer the technique which produces a carbon nanotube, especially the monolayer 25 carbon nanotube elongated to a substrate horizontal direction with high yield. Yet another object of this invention is to offer electronic devices, such as a transistor which is excellent in high-speed operation and high accumulation, using the carbon nanotube obtained by the above-mentioned technique.

[0021]

**[Means for Solving the Problem]**

According to this invention, a catalyst support substrate is obtained. The catalyst support substrate used for the vapor growth of a carbon nanotube is characterized by comprising: a principal surface including 35  
(a) a first field including a carbon nanotube vapor growth catalyst, and

(b) a second field including a metal containing at least one element

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selected from group 2 to 14 of periodic-table, or its compound (however, the matter chosen as the carbon nanotube vapor growth catalyst in the first field is excluded).

[0022]

5 Moreover, according to this invention, a growth method of a carbon nanotube characterized by growing up the carbon nanotube by supplying a material gas containing carbon to the catalyst support substrate is obtained.

[0023]

10 Moreover, according to this invention, a transistor is obtained. The transistor is characterized by comprising: a substrate, a catalyst-containing film formed on the principal surface of the substrate, a carbon nanotube elongated from the catalyst-containing film to a horizontal direction of the substrate, a first electrode linked to a part of the carbon nanotube by the side of the catalyst-containing film, a second electrode linked to a part of 15 the carbon nanotube by the other side, and a gate electrode that applies voltage to the carbon nanotube.

[0024]

20 Moreover, a growth method of the carbon nanotube is obtained. The growth method is characterized by including steps of: forming a catalyst-containing film with predetermined pattern on a substrate, and then growing up a carbon nanotube to a substrate horizontal direction by supplying carbon material containing gas.

[0025]

25 Moreover, a method for producing a transistor is obtained. The method is characterized by including steps of: forming a carbon nanotube elongated to a horizontal direction of a substrate by the above-mentioned method, forming a first electrode connected to a catalyst containing film side portion of the carbon nanotube and forming a second electrode connected to another side portion of the carbon nanotube, and forming a 30 gate electrode applying a voltage to the carbon nanotube.

[0026]

35 The catalyst support substrate concerning this invention has the surface in which a first field including metal or its compound containing a specific element and a second field including a carbon nanotube vapor growth catalyst exist. Therefore, it can grow up a carbon nanotube, especially a monolayer carbon nanotube suitably, and can achieve high yield. The second field of the substrate has the property to decompose the carbon

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compound used as the material gas of carbon nanotube growth, and is considered that high yield is achieved by the synergism of this property and the above-mentioned catalyst. Moreover, the second field has a function to adhere a catalyst and a substrate firmly, and thus, the carbon nanotube 5 stably arranged on a substrate can be obtained.

Moreover, according to the growth method of the carbon nanotube concerning this invention, the high quality carbon nanotube, especially monolayer carbon nanotube can be stably obtained with high yield. The obtained carbon nanotube is excellent in adhesion with a substrate, and can 10 be preferably applied for electronic devices, such as a transistor which is excellent in high-speed operation and high accumulation.

[0027]

Moreover, the transistor concerning this invention is excellent in the adhesion between a carbon nanotube and an electrode. Moreover, when a 15 monolayer carbon nanotube is used as a carbon nanotube, excellent device property in high-speed operation can be obtained stably, and the channel current which flows in a carbon nanotube is drastically changed by applying voltage. Therefore, an ideal transistor can be obtained.

[0028]

20 Since the manufacture method of the transistor according to this invention produces a carbon nanotube using above-mentioned growth method of carbon nanotube, a transistor with excellent high-speed operation property and reliability can be obtained with good manufacture stability.

[0029]

25 In this invention, since each of catalyst film and catalyst support film can be easily patterned by etching, a device with desired shape can be manufactured with sufficient yield.

[0030]

[Embodiment of the Invention]

30 In this invention, a carbon nanotube may be any of a monolayer carbon nanotube and a multilayer carbon nanotube. When a monolayer carbon nanotube is used, it can apply suitably for electron devices of which high-speed operation property is required, such as a transistor.

[0031]

35 In this invention, the surface of the catalyst-containing film can include:

(a) a first field including a carbon nanotube vapor growth catalyst,

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and

(b) a second field including a metal containing at least one element selected from group 2 to 14 of periodic-table, or its compound (however, the matter chosen as the carbon nanotube vapor growth catalyst in the first  
5 field is excluded).

Thus, the carbon nanotube which is excellent in substrate adhesion, a patterning property, and yield can be produced.

Examples of the carbon nanotube vapor growth catalyst includes simple substance metal, alloy, or compound containing either of iron-group  
10 (such as nickel, Fe and Co), platinum group (such as Pd, Pt and Rh), rare earth metal (such as La and Y), and transition metal (such as Mo and Mn). Among these, a metal or compound containing at least one selecting from group consisting of Fe, Ni, Co, Ru, Rh, Pd, Os, Ir, Pt, La, Y, Mo, and Mn is preferably used.

Moreover, examples of metal or compound that constitutes the second field includes at least one element selecting from group consisting of Al, Mo, Ti, Ta, Cr, Cu, Mn, Mg, Zr, Hf, W, Ru, Rh, Zn, and Sn. Among these, the oxide and hydroxide containing Al, Mo, Ti, Ta, Mg and these are preferably used. By using such material, a carbon nanotube, especially a monolayer carbon nanotube can be obtained with high yield.  
20

[0032]

In this invention, a structure can be used in which the catalyst-containing film is formed by laminating the catalyst support film and the catalyst film, and a carbon nanotube is grown up from the catalyst-containing film. In this case, the catalyst film covers a part of catalyst support film. These films can be formed by vacuum deposition, the  
25 sputtering method, or a CVD method.

When such structure is adopted, the catalyst support film can include a metal film containing at least one element selected from group 2 to 14 of periodic-table, and a film obtained by oxidizing or hydroxylating an upper part of the metal film. In this case, since a metal oxide film or the metal hydroxylation film serves as catalyst support and the metal film intervenes between the catalyst support and the substrate, the adhesion over the substrate becomes good, and the film quality of the catalyst support becomes good. Consequently, carbon nanotube which has good adhesive property over a substrate and has good electrical property can be formed with high yield on a substrate.  
30  
35

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Moreover, when the above-mentioned structure is adopted, the following advantage during process can be obtained. Firstly, since a process in which a metal film is formed and patterned to a predetermined shape, and upper part of the metal film is oxidized or hydroxylated can be used, patterning can be performed correctly and easily. Secondly, a metal oxide film and a metal hydroxylated film can be formed with good film quality and sufficient thickness controllability. For example, if these films are formed by the sputtering method, oxygen atom etc. desorbs, and sometimes a film with a desired composition may not be obtained. If the above-mentioned structure is adopted, fluctuation of such a composition can be reduced. Thirdly, the yield of a carbon nanotube can be controlled by controlling the structure of oxide film and hydroxylated film by controlling the treating condition of oxidization and hydroxylation. Thus, carbon nanotubes with desired density can be produced at an element area in which high yield is desired or at an element area in which low yield is desired. The reason why the yield of carbon nanotube changed with structure of oxide film and hydroxylated film is not obvious. But it is considered that the density and distribution of Lewis acid point of these films affect the yield.

An example of the above-mentioned structure includes a base layer of aluminum film as catalyst containing film, and a film, formed on the aluminum film, containing at least one selected from aluminum natural oxidation film, boehmite, alpha alumina, gamma alumina, delta alumina, and theta alumina. When such structure is used, the above-mentioned advantage becomes remarkable.

#### [0033]

In the transistor of this invention, a gate electrode can be formed in the upper part of a carbon nanotube, and it can also be formed adjacent to a carbon nanotube in the same field of the carbon nanotube, or it can also be formed in a substrate rear face. What is necessary is just to be formed in the location which produces electric field in a carbon nanotube.

#### [0034]

In the transistor of this invention, either of the first and the second electrodes functions as a source electrode and another electrode functions as a drain electrode. Arrangement of the first and the second electrode can take various configurations. The first and the second electrode can be formed discretely, and the gate electrode can be formed among these.

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Moreover, the second electrode can be formed to be discrete from the first electrode and to surround a part or whole of the first electrode.

[0035]

Hereafter, embodiments of the invention is explained with reference  
5 to figures.

[The first embodiment]

This embodiment relates to a method of growing up a monolayer carbon nanotube to a substrate horizontal direction. The film formation process of the carbon nanotube in this embodiment is shown in figure 14.

10 First, the metal film made of the first metal is formed on a substrate (step 101), and a catalyst support film made of a metal oxide or hydroxide is formed by oxidizing or hydroxylating the surface thereof (step 102).

Subsequently, a catalyst film containing the second metal or the compound of that metal is formed on the surface of the catalyst support film (step 103).

15 Subsequently, reduction treatment is performed in which the reducing gas is contacted on the substrate surface containing the catalyst film (step 104), and a monolayer carbon nanotube is grown up by performing gaseous-phase pyrolysis of the carbon raw material supplied on the catalyst film (step 105).

[0036]

20 Crystal substrates such as silicon, quartz, sapphire and MgO, alumina, amorphous substrates such as glass, and other metal substrates can be used for the substrate used in this embodiment. The substrate used in this embodiment is desired to be stable at temperature of 500 °C or more. It is because that it is required to be able to stand still over heat treatment  
25 at the time of carbon nanotube growth and heat treatment performed in order to obtain the oxide or hydroxide used as catalyst support.

[0037]

In this embodiment, the metal containing one or two or more elements selected from the group consisting of Al, Mo, Ti, Ta, Cr, Cu, Mn, 30 Mg, Zr, Hf, W, Ru, Rh, Zn, and Sn can be used as the first metal for example.

[0038]

Various kinds of metals which shows catalytic property in gaseous-phase pyrolysis growth of a monolayer carbon nanotube can be used as the second metal. For example, the metal or compound containing any one or 35 more kinds of iron-group (such as nickel, Fe, and Co), platinum group (such as Pd, Pt and Rh), rare earth metal (such as La and Y), and transition metals (such as Mo and Mn) can be used.

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## [0039]

In this embodiment, the combination of the catalyst film and the catalyst support film is important. That is, a material which can control sintering of the material which constitutes the catalyst film in the processing temperature of 500 °C or more is used as a material which constitutes the catalyst support film. For example, when the combination of iron (catalyst film) and silicon oxide (catalyst support film) is used, many iron fine grains are observed, and the yield of a monolayer carbon nanotube is drastically small. An aluminum oxide can be used as a suitable material for catalyst support film when iron is used as catalyst film.

## [0040]

Hereafter, the detail of each step shown in figure 14 is explained.

## [0041]

(i) Step 101 and step 102 (first metal film formation and its surface treatment)

In this embodiment, the catalyst support film made of metal oxide or metal hydroxide is formed by oxidizing the first metal film formed on the substrate. The first metal film does not need to be powder or a particle like before, and can be formed from a plane film. The configuration of the catalyst support film made of metal oxide or metal hydroxide is not limited, and it may be flat or may be a fine structure.

## [0042]

The thickness of the first metal film in this embodiment is not especially limited, and can be set up suitably. For example, it is enough to oxidize or hydroxylate a surface for the thickness of about one layer of atoms, or the thickness of about hundreds of microns.

## [0043]

The catalyst support film is obtained by oxidizing naturally, or oxidizing or hydroxylating chemically the surface of the first metal film. All of the surface of the first metal film is not necessary to be oxidized or hydroxylated, and oxidation or hydroxylation of a few atomic layers of the surface is sufficient. For example, the surface of aluminum can be exposed into air and the very thin natural oxidation film (about 1 to 10nm or less) can be formed.

## [0044]

An aluminum containing compound can also be used as catalyst support film. It is known that if an aluminum surface is boiled in water of

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90 to 100 °C, the surface becomes a aluminum oxide hydroxide (boehmite). Moreover, it is known that boehmite becomes gamma alumina by heating boehmite at about 600 °C. Gamma alumina is one of forms of alumina generally called transition alumina. In addition, delta alumina, theta alumina, kappa alumina, eta alumina, etc. are included in transition alumina. If boehmite is heated and raised to high temperature, it can be continuously changed to gamma, delta, theta, and, eventually at about 1200 °C, stable alpha alumina that has corundum structure. If such an aluminum containing compound is used as an insulating layer of the catalyst support film, a monolayer carbon nanotube can be efficiently produced.

[0045]

It is desirable to use a transition alumina from a viewpoint of the improvement in yield of a carbon nanotube. However, when alpha alumina is used, yield tends to be low, but a sufficient synergism with catalyst can be obtained, and a monolayer carbon nanotube can be manufactured. It is possible to control growth of a monolayer carbon nanotube using the difference in the synergistic effect of transition alumina and alpha alumina. For example, alpha alumina can be formed in the part where yield is made to be low, and a transition alumina can be formed in the part where yield is made to be high, and thereby yield can be controlled by the location. In this case, boehmite is changed to alpha alumina by processing at high temperature, and then aluminum film is formed and is changed to boehmite and a transition alumina by heat treatment. Thereby these different alumina can be made on one substrate. The temperature which forms a transition alumina is lower than the temperature which forms alpha alumina, so the alpha alumina formed previously does not deteriorate.

[0046]

Moreover, an alumina also can be obtained by anodizing the surface of aluminum in an acid. A part of thus obtained alumina is said to be gamma alumina. This anodic oxidation alumina is not necessary to have fine porosity, and a layer-like one which is used as an insulating layer can be used.

[0047]

Moreover, the surface of aluminum can be oxidized by dry process, such as exposing the surface of aluminum to the oxygen plasma. Moreover, it is also possible to form an oxide film selectively by anodization using a

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scanning tunneling microscope in air.

[0048]

As mentioned above, examples of the catalyst support film having a structure in which an aluminum film and an aluminum containing compound film are laminated on the substrate was explained. However, other metals can also be used. For example, a catalyst support film having a structure in which titanium film is formed on a substrate and a thin oxide film is formed in the surface can be used. In this case, the titanium oxide film can be easily formed by the natural oxidation in air. This also applies to Mo and Fe. A catalyst support film having a structure in which molybdenum and molybdenum-oxide film are laminated in this order on the substrate can be used. And a catalyst support film having a structure in which iron and iron-oxide film are laminated in this order on the substrate can be used.

[0049]

These catalyst support film can be also patterned when it is in a state of metal that is precursor. The so-called lift-off method in which resist is patterned by general optical exposure or electron-beam-lithography and metal film is formed and unnecessary part of the metal film is removed with the resist by solvent can be used. Also a method in which metal film is formed and resist is formed and patterned and the metal film is etched leaving a required part and can be used. Oxidization or hydroxylation of the first metal film is performed just after the formation of the first metal film or after the patterning of the first metal. In the case that the lift-off method or the etching is used, after forming a catalyst film containing the second metal, simultaneous patterning of the catalyst support film and the catalyst film can be performed by such technique. This is the so-called self-align method used for manufacture of a transistor. In this case, before forming the catalyst film, the first metal film should be oxidized or hydroxylated to form the catalyst support film.

[0050]

(ii) Step 103 (formation of the catalyst film)

About formation of the catalyst film, the same technique as the usual metal film formation can be used. For example, vacuum evaporation, a spatter, etc. can be used. Since a uniform film can be obtained by these methods and these methods can be easily performed in the procedure same as the metal patterning technique of the conventional metal, these methods

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are desirable. Moreover, the thickness of the catalyst film is desirable to be a thick that not covered thoroughly the catalyst support film. It is because the synergism by the combination of support and the catalyst will decrease remarkably if all support is covered thoroughly. That is, it is  
5 because it becomes a situation similar to a situation without the above-mentioned support. Therefore, the thickness of the catalyst film is desirable to be adjusted with the characteristic magnitude of the structure of the catalyst support film. For example, when below-mentioned boehmite is generated from aluminum with a thickness of 0.1 microns, the structure 10 of the shape of a petal of about several microns to hundreds nm arises. It is related that the volume increases in order to addition of oxygen atoms or hydroxyl groups to aluminum atoms during formation of boehmite. For this reason, the thickness of the catalyst film should be below about several microns to about 10 microns so that all of these boehmites may not be  
15 covered.

[0051]

Moreover, the catalyst metal film can also be formed, for example by the wet process using solutions of iron nitrate and 9 hydrate etc. When such a film formation method is adopted, the catalyst can be efficiently 20 formed on the surface of the catalyst support film, and the yield of a carbon nanotube can be improved.

[0052]

(iii) Step 104 (substrate surface reduction processing)

Reducing gas is contacted on the surface of the substrate which 25 passed through the above-mentioned process. Examples of reducing gas include H<sub>2</sub> and N<sub>2</sub> and the like. Thereby, the yield and quality of a carbon nanotube can be improved. The processing may be omitted if required.

[0053]

(iv) Step 105 (growth of a carbon nanotube)

After arranging the substrate, in which the catalyst support film and the catalyst film are formed, to film formation equipment, temperature of the growth ambient atmosphere is raised. Temperature is raised for example, under inert atmosphere. As a carbon material, various kinds of carbon containing material which is gases at the temperature of growth can 35 be used. Specifically, material that is gas at ordinary temperature (such as methane (CH<sub>4</sub>), ethylene (C<sub>2</sub>H<sub>4</sub>) and a carbon monoxide (CO)), or material that is solid or liquid at ordinary temperature and gas at a raised

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temperature of growth temperature (such as phenanthrene, benzene, ethanol and methanol) can be used. By this, gaseous-phase pyrolysis growth of the monolayer carbon nanotube can be performed on the surface of the catalyst-containing film which consists of the above-mentioned catalyst support film and catalyst film. In this case, in order to promote reduction of a catalyst metal, hydrogen can be supplied with carbon material. Thereby, catalysis can be increased and the yield of a monolayer carbon nanotube can be increased.

[0054]

Supply of the carbon to a catalyst and catalyst support can be performed by the method other than the pyrolysis of the carbon material under the elevated temperature as mentioned above. Supply can be performed by decomposition of carbon material using plasma of argon and hydrogen etc., or by evaporation of carbon-containing solid such as a carbon rod by laser ablation etc.

[0055]

Although selective growth of a monolayer carbon nanotube can be performed by using the above-mentioned patterned catalyst and catalyst support, the directivity of the manufactured monolayer carbon nanotube is random. It is known that a direction of a monolayer carbon nanotube will gather by applying outer field such as electric field or magnetic field. Also in the above-mentioned patterned catalyst and catalyst support, in case a carbon raw material is supplied, it is possible to arrange the direction by applying outer field such as electric field, magnetic field, or rotation of the substrate.

[0056]

[The second embodiment]

Hereafter, the desirable embodiment of the transistor concerning this invention is explained with reference to figures.

[0057]

Figure 9 shows an example of the structure of the transistor concerning this invention. Figure 9 (a) shows the sectional view of the transistor, and figure 9 (b) shows the plan view of the transistor. The transistor of this embodiment has the structure in which silicon oxide film 102 is formed on a silicon substrate 101 and the element part is formed on it. The element part is composed of a gate section which consists of an insulating film 119 and a gate metal film 120, a source electrode 130 and a

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drain electrode 131 formed in both the side of the gate section, and the carbon nanotube 105 which connects these electrodes. A carbon nanotube 105 grows up to be a substrate horizontal direction from the catalyst film 150 formed on the catalyst support film 104. In this transistor, a carbon 5 nanotube 105 functions as channel region. That is, by applying an voltage to the gate electrode which consists of an insulating film 119 and the gate metal film 120, the conductivity of a carbon nanotube 105 changes and, thereby, the current which flows between the source electrode 130 and the drain electrode 131 changes.

10 [0058]

Figure 10 shows another example of the transistor concerning this invention. Although the transistor of this embodiment has the almost same structure as the transistor shown in figure 9 except that the insulating film 119 and the gate metal film 120 is formed so as to straddle 15 the source electrode 130 and the drain electrode 131.

[0059]

Figure 11 shows another example of the transistor concerning this invention. The transistor is a transistor of so-called backgate type, and, unlike the transistors of figure 9 and figure 10, the gate electrode 100 is 20 formed in the rear face of a silicon substrate 101. The conductive controllability of a carbon nanotube 105 may fall a little since the gate electrode is formed in a location separated from the carbon nanotube 105 in the transistor of this embodiment. On the other hand, the advantage that formation of a gate electrode becomes easy is acquired.

25 [0060]

In this invention, the source electrode and the drain electrode can be arranged in various arrangements. Figure 12 shows an example of arrangement of source-drain electrodes. The drain electrode 131 is formed so that it is discrete from the source electrode 130 and it surrounds a part 30 of the source electrode 130. The gate metal film 120 is formed between the source electrode 130 and the drain electrode 131. The carbon nanotube 105 is formed so that it straddles the source electrode 130 and the drain electrode 131. The carbon nanotube 105 is grown up to a substrate horizontal direction from the catalyst support film 104. By arranging a 35 source drain electrode as such arrangement, connection by the carbon nanotube carbon nanotube 105 between two electrodes is ensured. That is, when the carbon nanotube 105 is grown up in vapor phase from the catalyst

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support film 104, the direction of growth can take all directions in a substrate plane. In the case that the arrangement of figure 12 is adopted, even when the growth directions of a carbon nanotube 105 are various, the source electrode 130 and the drain electrode 131 can be certainly connected with a carbon nanotube 105.

[0061]

Figure 13 shows another arrangement of a source drain electrode. In this arrangement, the drain electrode 131 is formed around the source electrode 130 so that it is discrete from the source electrode 130 and it covers the periphery of the source electrode 130. The gate metal film 120 is formed between the source electrode 130 and the drain electrode 131. The carbon nanotube 105 is formed so that it connects with both the source electrode 130 and the drain electrode 131. The carbon nanotube 105 grows up to be a horizontal direction within a substrate plane from the catalyst support film 104. In the case that this arrangement is taken, even when the carbon nanotube 105 grows up to any directions, electrical connection between the source electrode 130 and the drain electrode 131 can be achieved. Electrical connection by the carbon nanotube 105 can be further ensured by setting up suitably the distance between the source electrode 130 and the drain electrode 131 in consideration of the growth conditions of the carbon nanotube 105.

In the transistor shown above, the source electrode 130 and the drain electrode 131 can be consists of monolayers or laminated film of gold, platinum, titanium and the like. As the gate metal film 120, at least one metal such as aluminum, gold, titanium, or a tungsten can be used.

[0062]

Next, an example of a method for manufacturing the transistor shown in figure 9 is explained with reference to figure 17 - figure 19.

[0063]

First, silicon oxide 102 and the catalyst support material 103 are formed on a silicon substrate 101 as shown in figure 17 (a). The catalyst support material 103 has the structure in which TiN, aluminum, and an aluminum oxide are laminated in this order. TiN is used as adhesion film which improves the adhesion between silicon oxide 102 and the aluminum on it.

[0064]

Next, after forming a mask on the catalyst support material 103, the

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catalyst support material 103 is patterned by dry etching, and the catalyst support film 104 is formed. The catalyst film 150 containing Fe is formed on the catalyst support film 104 by vacuum deposition. The thickness of the catalyst film 150 is about 2.5nm. By adopting such thickness, the catalyst films 150 are scattered on a part of surface of the catalyst support film 104, and both the catalyst support film 104 and the catalyst film 150 are exposed. In addition, although Fe is used as a material of the catalyst film 150 here, other materials can also be used.

[0065]

10 Next, the substrate is arranged in a CVD film formation chamber, and the carbon nanotube 105 is grown up from the catalyst film 150 by supplying material gas such as methane and acetylene. A carbon nanotube 105 is elongated to the horizontal direction within a substrate plane (figure 17 (c)). In order to make the carbon nanotube of monolayer structure 15 elongate to the horizontal direction within a substrate plane, it is important to choose appropriately the catalyst film and the material of the support, and growth temperature.

[0066]

Next, a resist 106 is formed on a carbon nanotube 105 (figure 17 (d)).

[0067]

20 Next, as shown in figure 18 (a), a resist 106 is exposed through the mask 108 having opening, and the soluble field 110 that dissolves in a developer is formed. Then, by treating the surface of the resist 106 with predetermined solutions such as monochlorobenzene, the resist alteration layer 112 which is hard to dissolve in a developer is formed (figure 18 (b)). Then, an exposure part is dissolved by being immersed in a developer 25 (figure 18 (c)). At this time, opening of the resist 106 becomes an inverse tapered shape, as shown in figure 18 (c).

[0068]

30 An electrode film 116 is vapor-deposited all over the substrate using the resist mask (figure 18 (d)).

Then, the resist 106 and the electrode film 116 are removed by a solvent which dissolves the resist 106 (the lift-off method). The state when the resist is removed is shown in figure 19 (a).  
35 At the above-mentioned process, since opening of the resist 106 has an inverse tapered shape as shown in figure 18 (c), the lift off can be performed easily.

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## [0069]

Next, the resist 118 which has opening between electrode layers 116 is formed (figure 19 (b)), and an insulating film 119 and the gate metal film 120 are formed in this order by using the resist 118 as mask (figure 19 (c)).

5 Then, exfoliation processing of the resist mask is performed by using a solvent which dissolves the resist 118. And the resist 118, the unnecessary insulating film 119 and the unnecessary gate metal film 120 those are formed on the resist 118 are removed.

## [0070]

10 According to the above processes, the transistor having the structure shown in figure 19 (d) is obtained. This transistor is driven where either of the electrode films 116 is used as a source electrode and another electrode film 116 is used as a drain electrode. With this embodiment, electrode layers 116 are connected by growing up a carbon nanotube 105 horizontally from the catalyst film 150. Therefore, electrodes can be connected with higher accuracy compared with the method which arranges the carbon nanotube distributed in a solvent to inter-electrode. Moreover, the contact resistance between the carbon nanotube 105 and the electrode film 116 can be reduced relatively.

## 15 [0071]

20 Embodiments of this invention are explained above, but each material which constitutes the device and each process which constitutes the processes can be changed suitably. For example, a resist opening of an inverse tapered shape is formed in figure 18, but such process may not be adopted, and resist opening of such an inverse tapered shape configuration may be formed at the process shown in figure 19 (b).

25 Moreover, although the above-mentioned embodiments are explained as a process which manufactures the transistor of the structure shown in figure 9 and figure 19 (d), it can also apply to manufacture of the transistor having the structure of figure 10 or figure 11.

## 30 [0072]

## [Example]

## [Example 1]

35 In this example, an example in which boehmite is used as a catalyst support film material and iron is used as a catalyst film material and a monolayer carbon nanotube is grown up on the substrate is shown. Firstly, 20nm of aluminum was vapor-deposited on a silicon substrate.

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Next, this was heated about 30 minutes in the boiled water of 100 °C, and aluminum changed to aluminum oxide hydroxide (alias name boehmite). Furthermore, it was heated in air at 600 °C for 1 hour, it changed into gamma alumina, and this was used as catalyst support film. Then, 2nm of 5 iron was vapor-deposited on gamma alumina, and it was used as the catalyst.

[0073]

This sample was introduced into the electric furnace with the diameter of about 2 inch, and temperature was raised to 800 °C in argon 10 atmosphere. When the temperature reached 800 °C, the atmospheric gas was changed from argon to methane (99.999%), and was maintained for 5 minutes. Then, the atmospheric gas is changed to argon gas again, and temperature was lowered until it became a room temperature. The 15 photograph of thus obtained deposit is shown in figure 1 observed by the scanning electron microscope.

[0074]

Figure 3 is the transmission electron microscope photograph of the deposit shown in figure 1. From the observation result of figure 3, it was confirmed that the deposit was a monolayer carbon nanotube.

[0075]

On the other hand, figure 2 is the Raman spectrum of the deposit of figure 1. Excitation light is light of Ar laser with a wavelength of 488nm, and the spot size of the laser is about 1 micron. In this Raman spectrum, a big peak (so-called tangential mode) around the  $1590\text{cm}^{-1}$ , and a peak (so-called bleeding mode) in the range of  $100\text{-}300\text{cm}^{-1}$  were observed.

Tangential mode and bleeding mode are spectrums characteristic to a monolayer carbon nanotube, and from these, the generation of the monolayer carbon nanotube was confirmed.

[0076]

It is known that the location of the peak in bleeding mode and the diameter of a monolayer carbon nanotube have a unique relation. Since the peak was distributed in a range of  $100\text{cm}^{-1}$  to  $250\text{cm}^{-1}$ , it revealed that the diameter of a monolayer carbon nanotube was about 0.9nm to about 2nm.

[0077]

Although same deposit was observed even at 700 °C, yield decreased as compared with that at 800 °C. Before introducing methane, it was

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possible to make yield increase by reducing about 5 minutes in a hydrogen atmosphere. The same deposit was observed at 600 to 900 °C by performing reduction processing.

[0078]

5 [Example 2]

Although the catalyst was formed on the catalyst support which consists of boehmite in the example 1, iron was formed on silicon oxide in this example, and then, the carbon nanotube was grown up. Although the monolayer carbon nanotube was obtained in this example, yield was  
10 drastically low compared with the example 1.

[0079]

[Example 3]

When iron (catalyst) metal film thickness was changed from 1nm to 5nm in the example 1, it was confirmed, with scanning electron microscope observation and a Raman spectrum, that a monolayer carbon nanotube was obtained as well as an example 1. Since the surface of boehmite and a transition alumina has the structure of the shape of a petal with a magnitude of about hundreds of nm to several microns, it is considered that growth of a monolayer carbon nanotube is possible also with the metal film thickness of about several microns iron.  
20

Figure 15 and figure 16 show the result of appearance observation of boehmite formed as same as example 1 with the scanning electron microscope. It was confirmed that boehmite had petal-like structure.

[0080]

25 [Example 4]

In this example, aluminum was vapor-deposited on a silicon substrate, and it was left in air about one or two days. Thus, catalyst support was obtained. 2nm of iron was vapor-deposited as a catalyst on the catalyst support (aluminum natural oxidation film). Then, the monolayer carbon nanotube was grown up by delivering methane under atmosphere of 800 °C as well as the example 1. Figure 4 shows an image of obtained carbon nanotube observed by a scanning electron microscope. Although there is a shade compared with that of figure 1, this is because that the amount of the deposit varies by the location.  
30

35 [0081]

Figure 5 is a Raman spectrum of the carbon nanotube shown in figure 4. Tangential mode and bleeding mode that are specific to a

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monolayer carbon nanotube were observed.

[0082]

[Example 5]

This example is an example in which the catalyst support film was patterned. First, silicon oxide of about 15nm was formed on the silicon substrate by thermal oxidation. Next, a resist with a thickness of about 1.8 microns for optical exposure was patterned, and 20nm of aluminum was vapor-deposited on it, and this was boiled in 100 °C water for 30 minutes, and aluminum became boehmite. Above this, 2nm of iron as a catalyst was vapor-deposited, and boehmite and iron on the resist was lifted-off in acetone. In this way, the support/catalyst structure which consists of the patterned boehmite/iron was formed.

[0083]

Then, the monolayer carbon nanotube was formed by delivering methane gas at the 800 °C as well as the example 1. Figure 6 shows an image of obtained carbon nanotube observed by a scanning electron microscope. A catalyst and support did not exist in a center section as shown in figure 6, and the deposit growing from this part was not observed. On the other hand, many deposits were observed at where that was both side of that part and that was where the catalyst and support were formed.

[0084]

Figure 7 shows the Raman spectrum of the carbon nanotube shown in figure 6. Tangential mode and bleeding mode those are specific to a monolayer carbon nanotube were observed.

[0085]

In this example, the direction can be arranged in the direction of electric field by applying the direct-current electric field more than about 0.5 MV/m or by applying the alternating current electric field of 0.1 MV/m or more. Figure 8 is an example of an equipment configuration which realizes such a thing. This equipment is equipped with an electrode 3, a counterelectrode 4, and a substrate support 8 arranged therebetween in a reaction tube 2. Power is supplied to the electrode 3 and the counterelectrode 4 through feeders 6 and 7, respectively. The heater 1 for heating is formed in the perimeter of a reaction tube 2, and the ambient temperature of a reaction tube 2 can be adjusted. The electrode 3, a counterelectrode 4, and the substrate support 8 is preferably made of material which can resist the temperature at the time of growth. The

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substrate support 8 is preferably made of quartz etc. As the electrode 3 and the counterelectrode 4, metal film, which can resist the temperature at the time of growth such as platinum, formed on the mesh structure of a quartz is used.

5 [0086]

When a carbon nanotube is grown up by using this equipment, the substrate 5 on which the catalyst support film and the catalyst film is formed is arranged between the electrode 3 and the counterelectrode 4, and electric field are generated between two electrodes. Since the mesh-like hole is formed in the electrode 3 and the counterelectrode 4, a carbon material is efficiently supplied to a substrate-like catalyst through the hole.

10 [0087]

[Example 6]

In this example, transistor using a monolayer carbon nanotube was produced and evaluated. As well as example 4, 20nm of aluminum was vapor-deposited and leaved for two days in air, and 2nm of iron was vapor-deposited as a catalyst, and the monolayer carbon nanotube was grown up. Growth temperature was 800 °C. Then, the process shown in figure 17 (d), figure 18 and figure 19 in the second embodiment of was carried out, and the transistor was produced. In figure 17 to figure 19, the insulating film 119 was titanium oxide film (thickness : 2nm) obtained by natural oxidation of the titanium film. The gate metal film 120 was platinum film (thickness : 10nm). The source electrode 130 and the drain electrode 131 were gold film (thickness : 10nm). This transistor has the almost same structure as shown in a figure 9, but the source electrode 130 and the drain electrode 131 are arranged as the arrangement of figure 12 instead of the arrangement of figure 9 (b).

20 [0088]

The evaluation of the obtained transistor is shown in figure 20. In figure 20, an axis of abscissa shows voltage between source and drain, and the axis of ordinate shows drain current value. The I-V property was evaluated by grounding the substrate and changing voltage applied to gate voltage from -1V to 1V by 0.1V. It was confirmed that the transistor obtained by the example showed a good property.

25 [0089]

[Effect of the Invention]

As mentioned above, the catalyst support substrate of this invention

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as explained above has the principal surface on which the first field including a carbon nanotube vapor growth catalyst and the second field including material containing a specific element are exposed. Therefore, the carbon nanotube having an excellent adhesion with a substrate and an  
5 excellent patterning property can be obtained with high yield by the synergism of these fields. Moreover, the monolayer carbon nanotube which is excellent in an electrical property can be obtained stably.

[0090]

Moreover, according to the growth method of the carbon nanotube  
10 concerning this invention, the high quality carbon nanotube, especially monolayer carbon nanotube can be stably obtained with high yield. The obtained carbon nanotube is excellent in adhesion with a substrate, and can be applied suitably for electronic devices, such as a transistor which is excellent in high-speed operation property and high accumulation property.  
15 [0091]

Moreover, since the transistor concerning this invention has the structure in which the carbon nanotube elongated from the catalyst-containing film to the substrate horizontal direction connects with an electrode, adhesion between the carbon nanotube and the electrode is  
20 excellent. Moreover, when a monolayer carbon nanotube is used as a carbon nanotube, an excellent device property in high-speed operation can be acquired stably, and the channel current which flows in a carbon nanotube changes sharply by applying voltage, thereby an ideal transistor can be obtained.

25 [0092]

Since, the manufacture method of the transistor of this invention forms a carbon nanotube part using the above-mentioned growth method of carbon nanotube, the transistor excellent in high-speed operation property and dependability can be obtained with good manufacture stability.

30 [0093]

In this invention, when the configuration in which the catalyst film was formed to cover some catalyst support film on the catalyst support film is adopted, the adhesion over the substrate becomes good, and the film quality of catalyst support becomes good. Consequently, carbon nanotube excellent in the adhesion over a substrate and excellent in the electrical property can be obtained with high yield on a substrate. In addition, the patterning property of the catalyst support film, a thickness controllability,

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and manufacture stability can be improved.

[Brief Description of the Drawings]

[Figure 1] It is figure showing a scanning electron microscope observation image of the monolayer carbon nanotube obtained in the example.  
5 [Figure 2] It is figure showing a Raman spectrum of the monolayer carbon nanotube shown in figure 1.  
[Figure 3] It is figure showing a transmission electron microscope observation image of the monolayer carbon nanotube shown in figure 1.  
10 [Figure 4] It is figure showing a scanning electron microscope observation image of the monolayer carbon nanotube obtained in the example.  
[Figure 5] It is figure showing a Raman spectrum of the monolayer carbon nanotube shown in figure 4.  
[Figure 6] It is figure showing a scanning electron microscope observation  
15 image of the monolayer carbon nanotube obtained in the example.  
[Figure 7] It is figure showing a Raman spectrum of the monolayer carbon nanotube shown in figure 6.  
[Figure 8] It is figure showing an example of carbon nanotube growth equipment.  
20 [Figure 9] It is figure showing an example of the configuration of the transistor concerning this invention.  
[Figure 10] It is figure showing an example of the configuration of the transistor concerning this invention.  
[Figure 11] It is figure showing an example of the configuration of the transistor concerning this invention.  
25 [Figure 12] It is figure showing an example of the configuration of the transistor concerning this invention.  
[Figure 13] It is figure showing an example of the configuration of the transistor concerning this invention.  
30 [Figure 14] It is figure showing a flow of the growth method of the carbon nanotube concerning this invention.  
[Figure 15] It is figure showing a scanning electron microscope observation image of the catalyst support film produced in the example.  
[Figure 16] It is figure showing a scanning electron microscope observation  
35 image of the catalyst support film produced in the example.  
[Figure 17] It is figure for explaining a manufacture method of the transistor concerning this invention.

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[Figure 18] It is figure for explaining a manufacture method of the transistor concerning this invention.

[Figure 19] It is figure for explaining a manufacture method of the transistor concerning this invention.

5 [Figure 20] It is figure showing a property of the transistor obtained in the example.

[Description of Notations]

- 1 Heater for Heating
- 10 2 Reaction Tube
- 3 Electrode
- 4 Counterelectrode
- 5 Substrate
- 6 Feeder
- 15 7 Feeder
- 8 Substrate Support
- 100 Gate Electrode
- 101 Silicon Substrate
- 102 Silicon Oxide
- 20 103 Catalyst Support Material
- 104 Catalyst Support Film
- 105 Carbon Nanotube
- 106 Resist
- 108 Mask
- 25 110 Soluble Field
- 112 Resist Alteration Layer
- 116 Electrode Film
- 118 Resist
- 119 Insulating layer
- 30 120 Gate Metal Film
- 130 Source Electrode
- 131 Drain Electrode
- 150 Catalyst Film

2004-67413A**[Abstract]**

**[Problem(s)]** To offer a technique which produces a monolayer carbon nanotube having excellent adhesion property to a substrate and having excellent patterning property, with high yield.

5 **[Means for solving the problem]** Catalyst film 150 is formed on catalyst support film so that the catalyst film 150 covers a part of catalyst support film 104. A monolayer carbon nanotube is grown up from the catalyst film 150.

**[Selected figure]** Figure 17

10

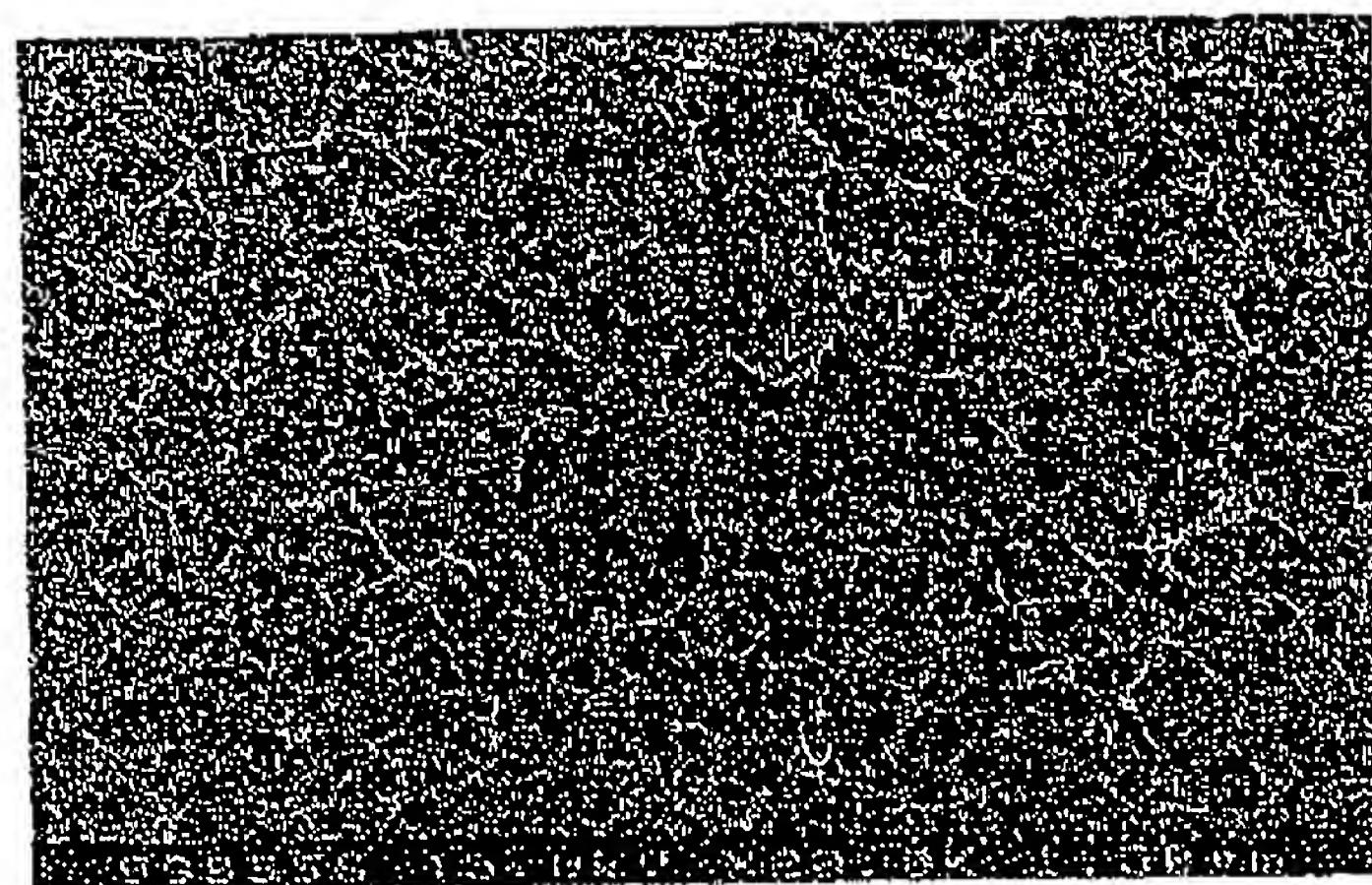


Fig. 1

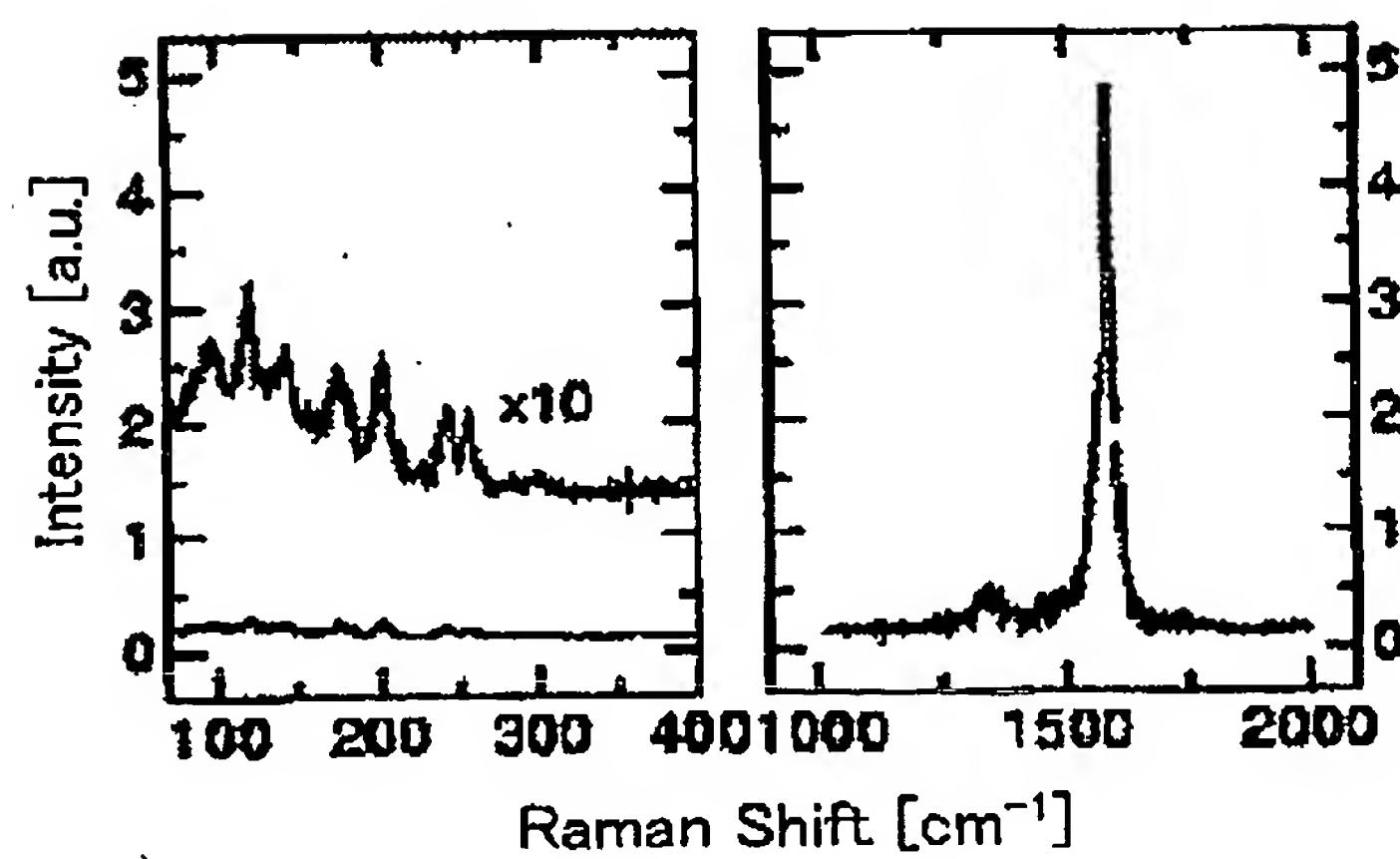


Fig. 2

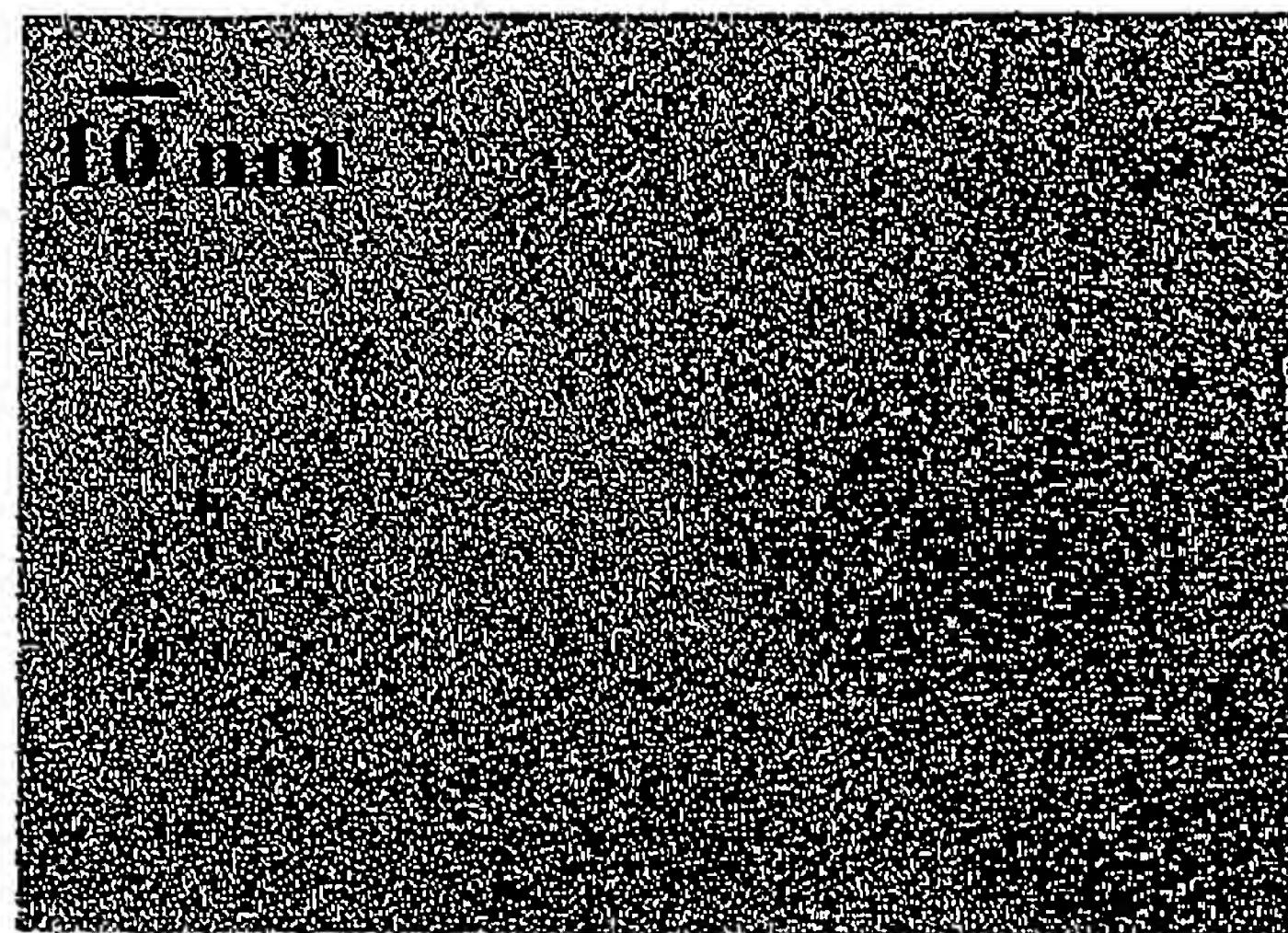


Fig. 3



Fig. 4

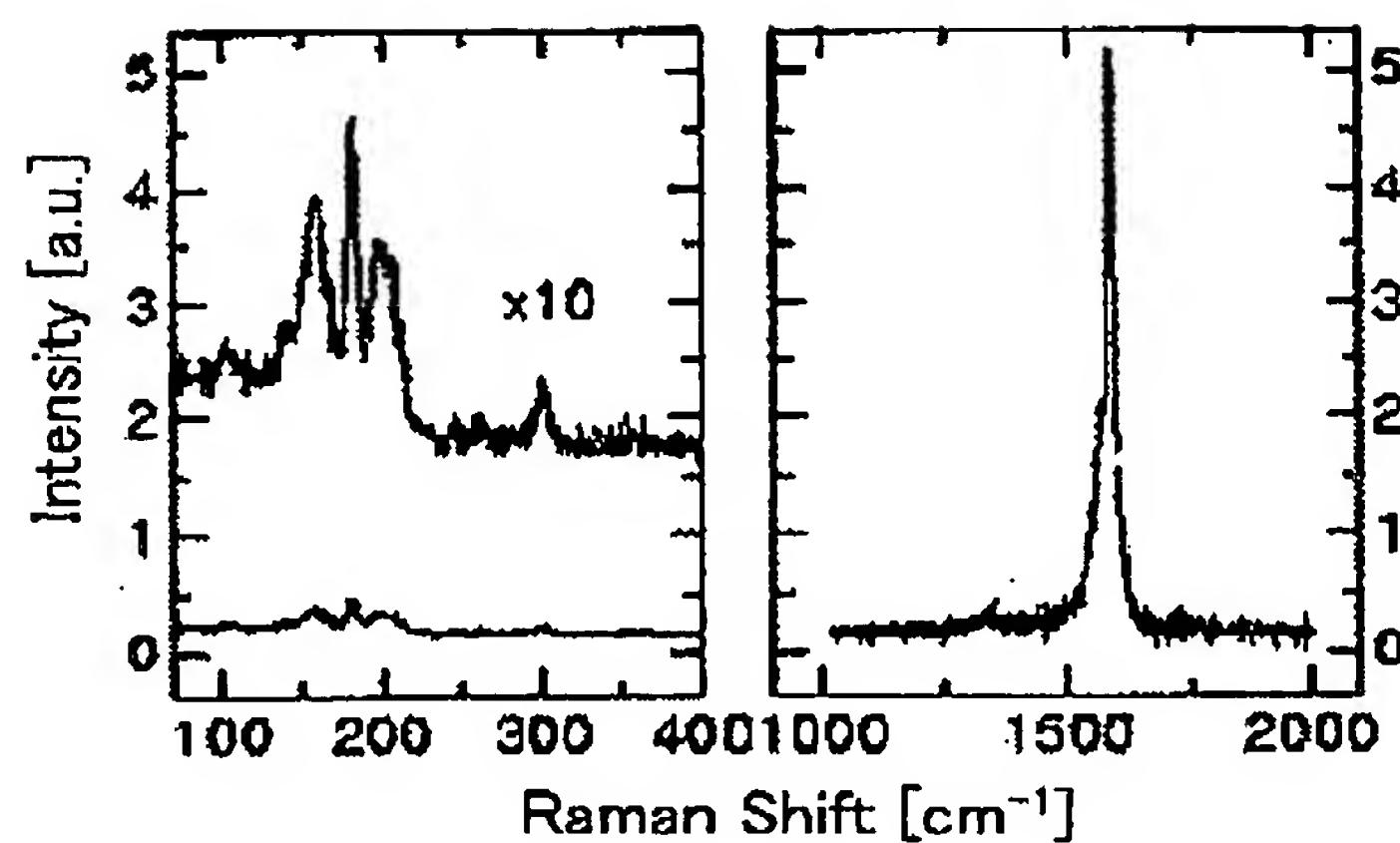


Fig. 5

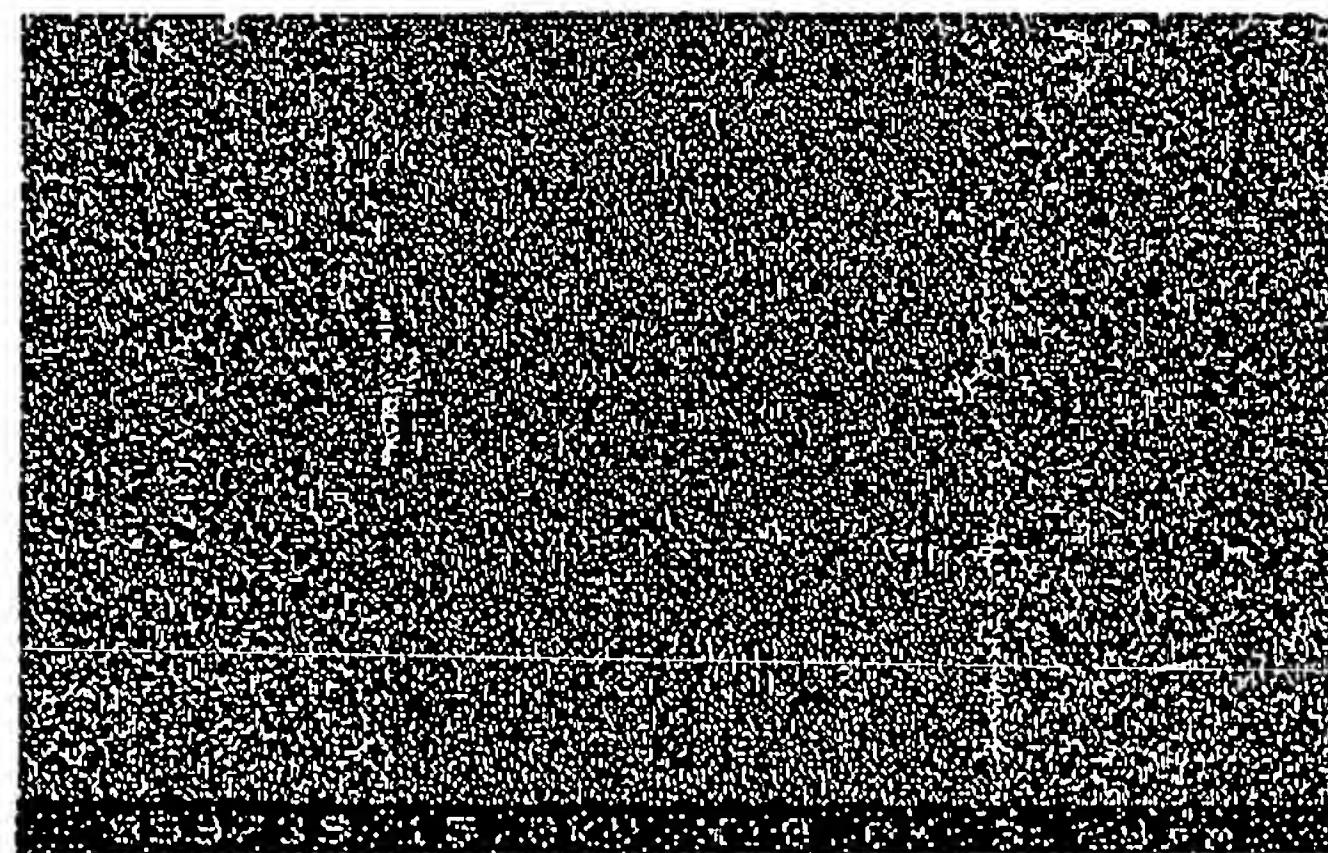


Fig. 6

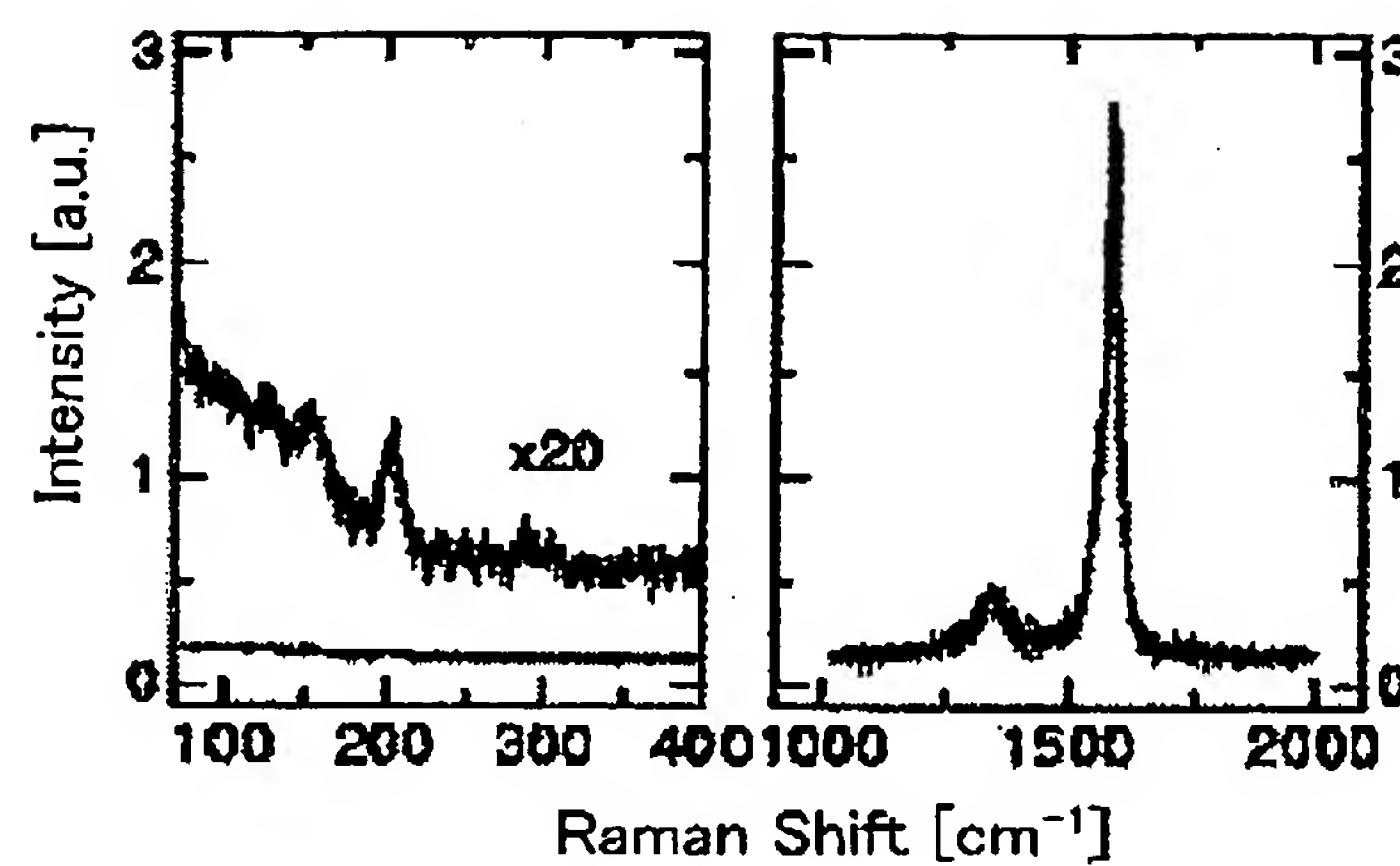


Fig. 7

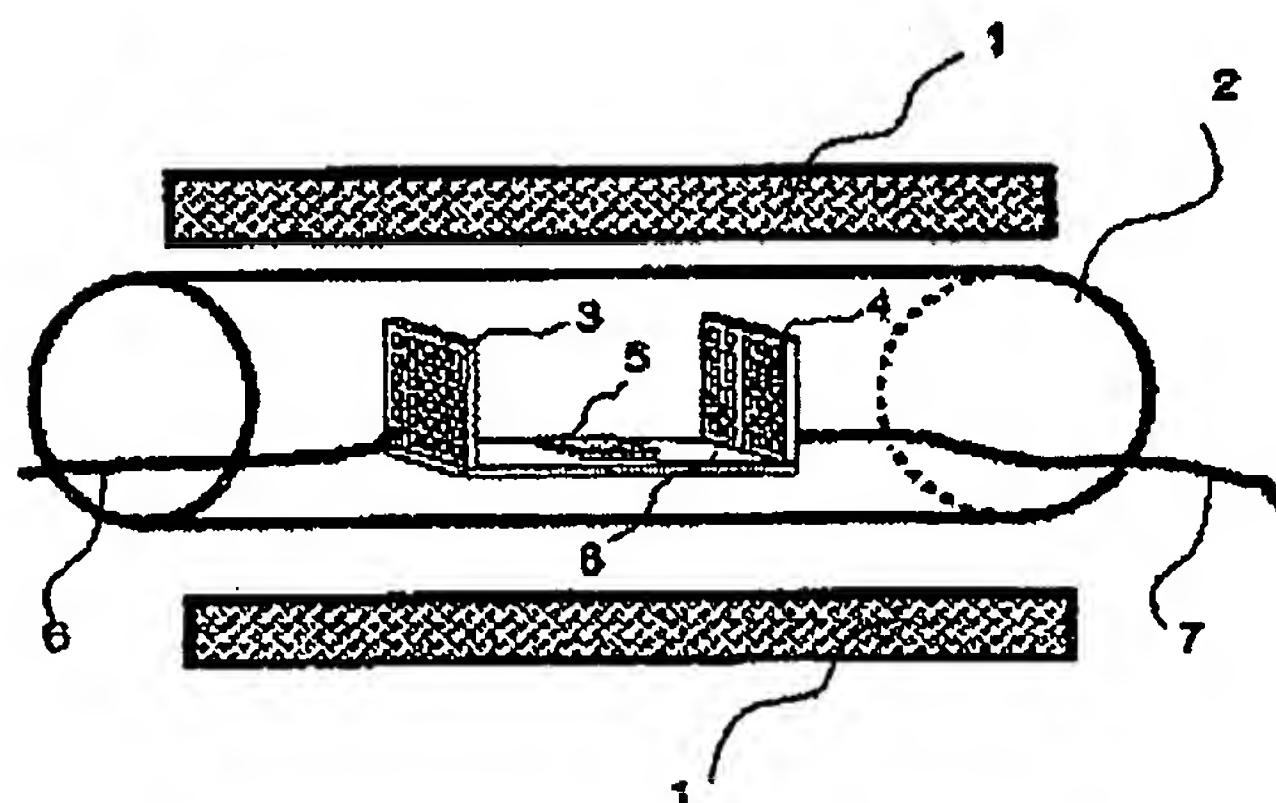


Fig. 8

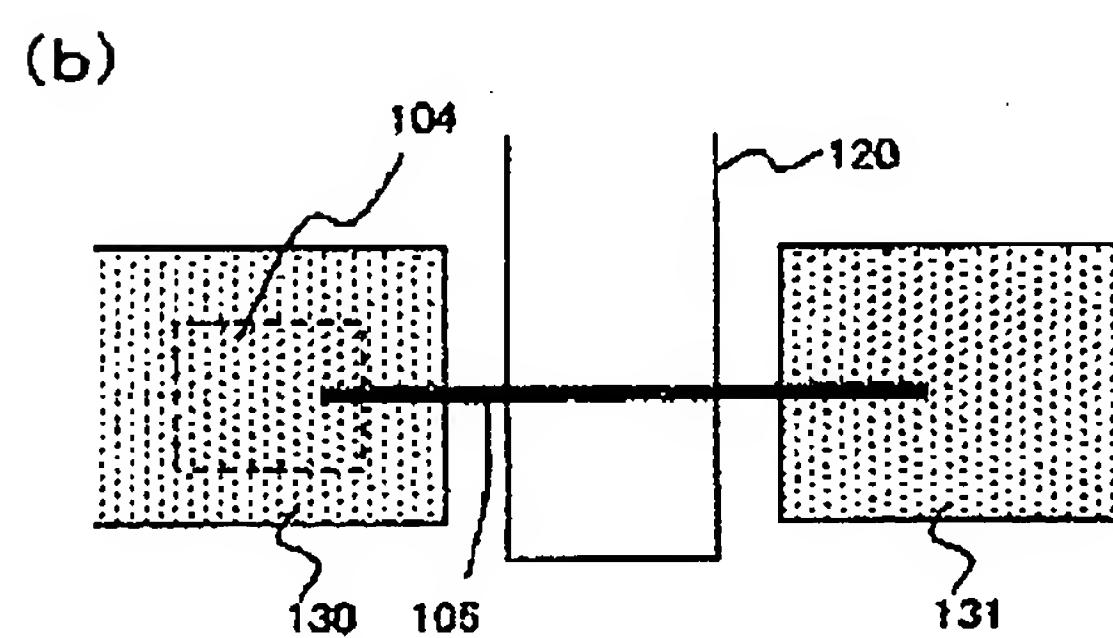
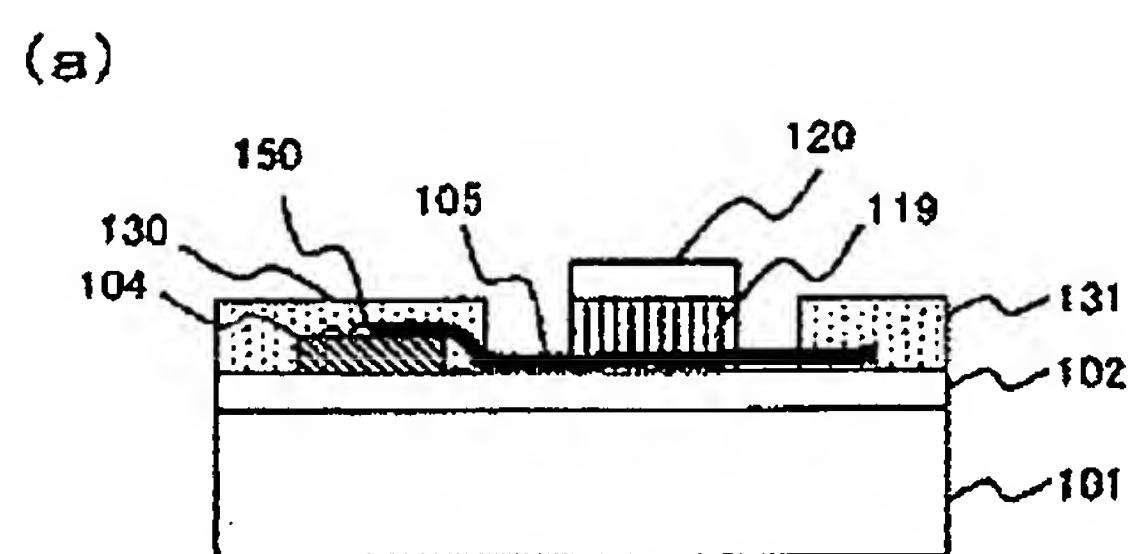


Fig. 9

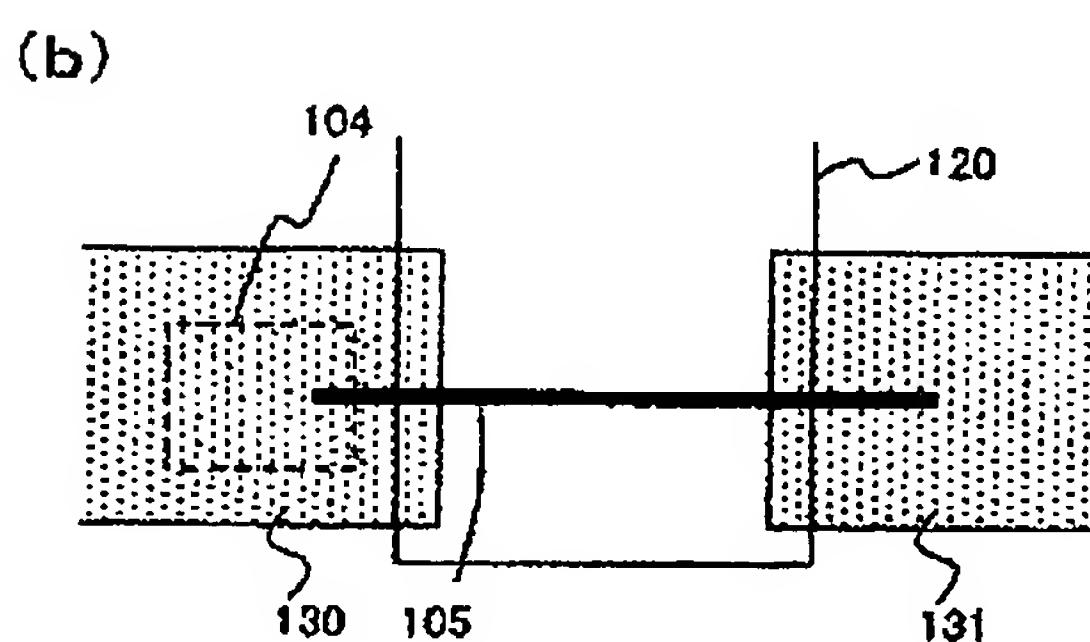
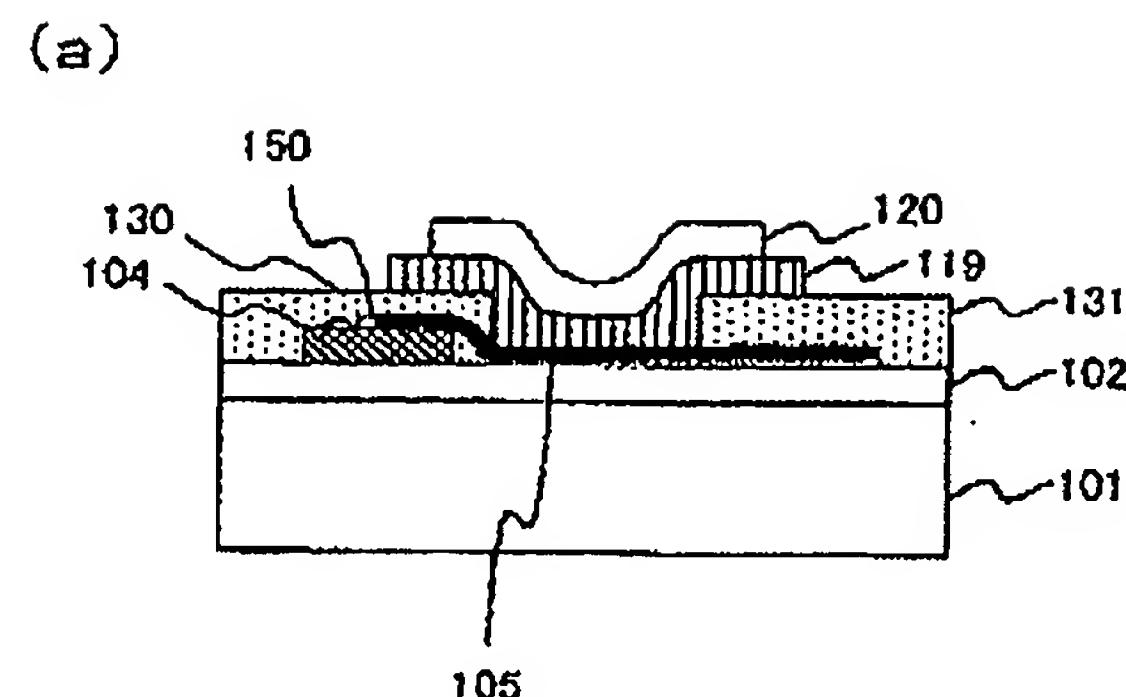
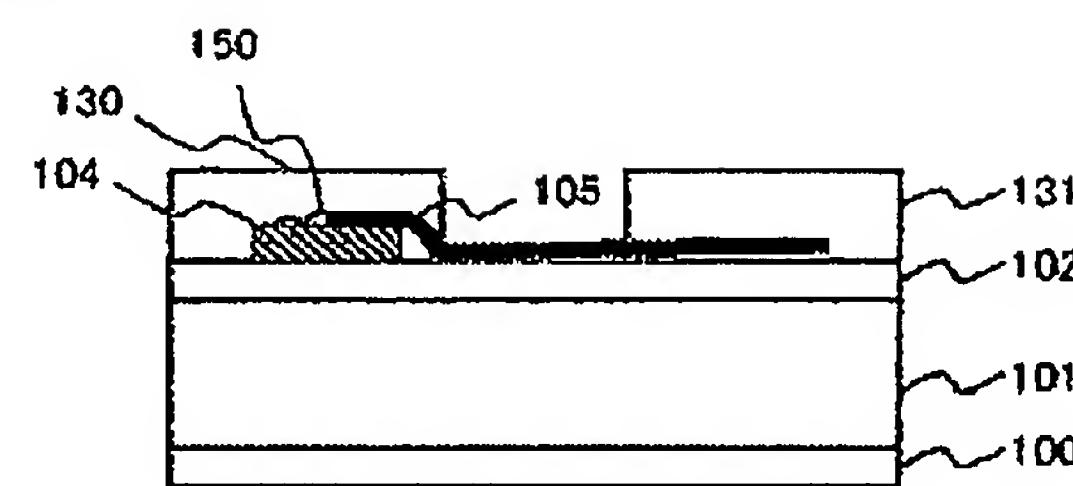


Fig. 10

(a)



(b)

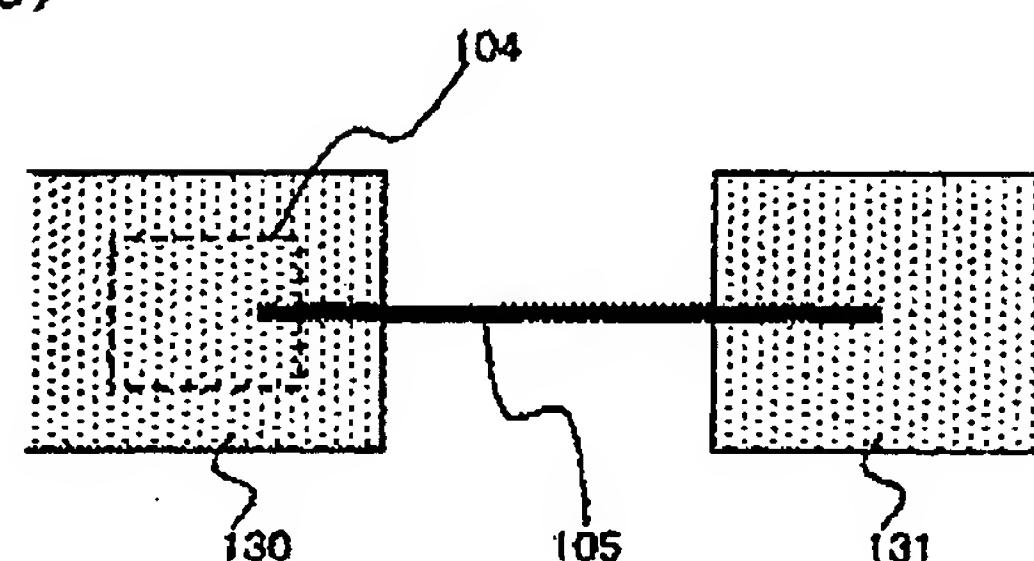


Fig. 11

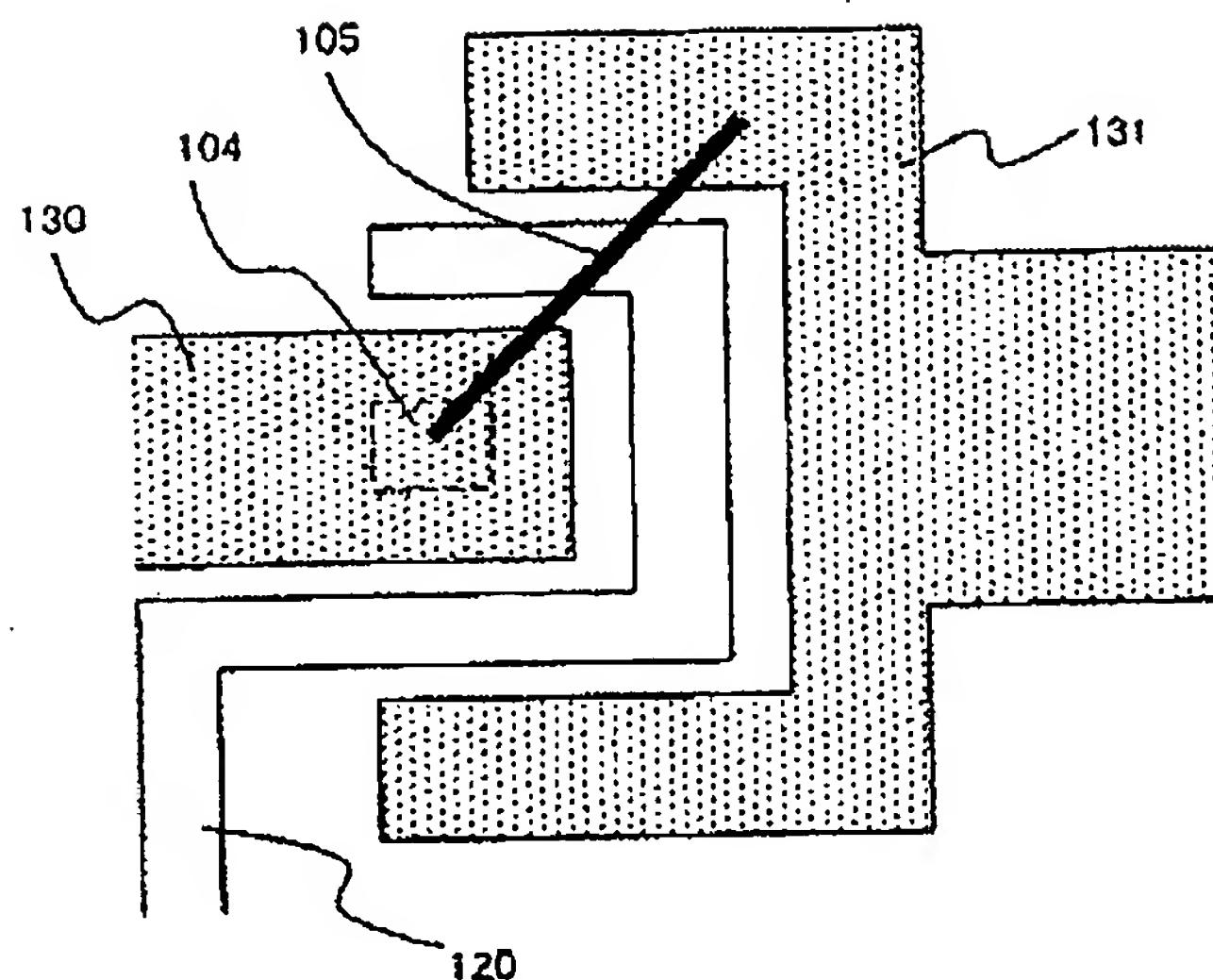


Fig. 12

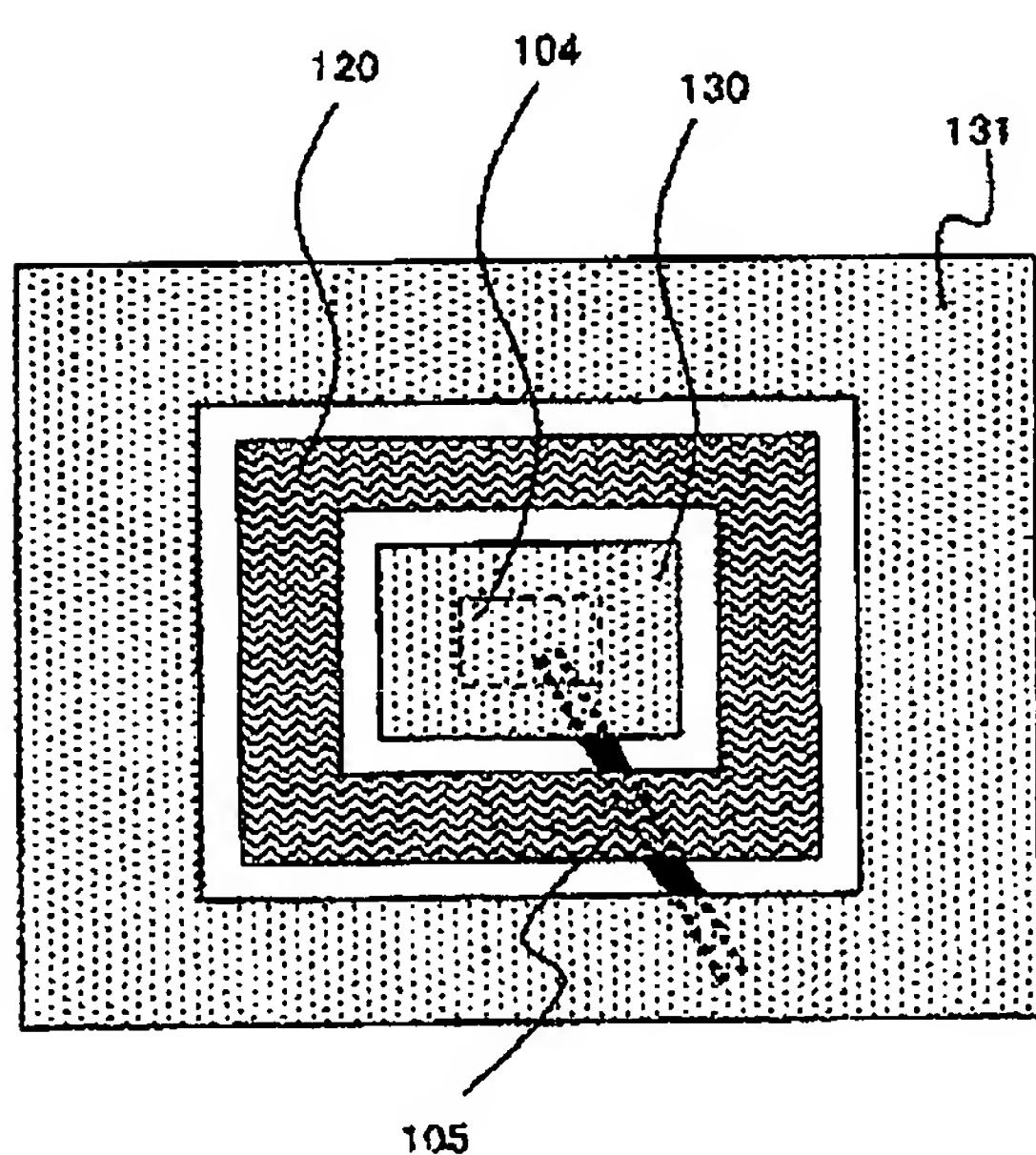


Fig. 13

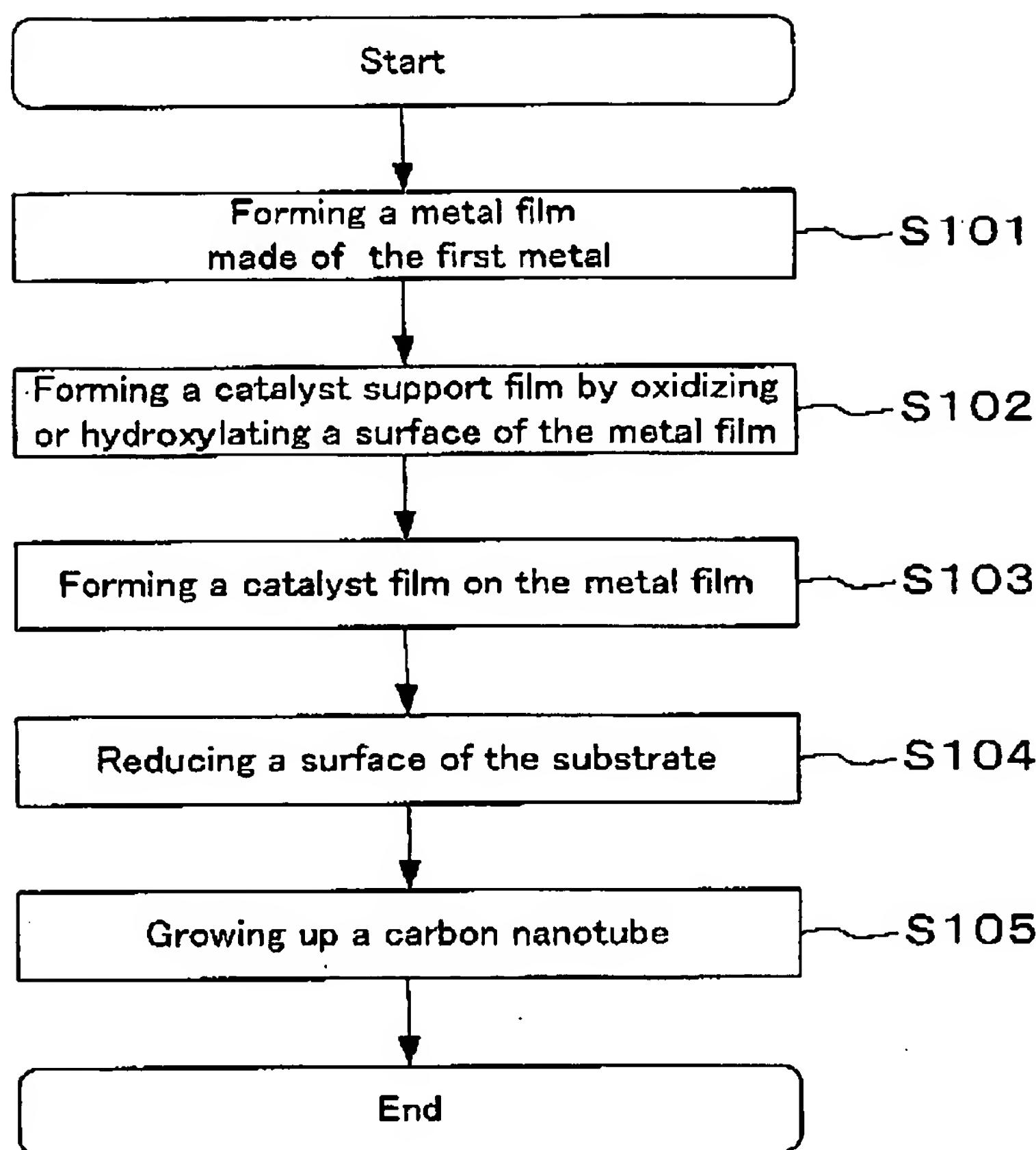


Fig. 14

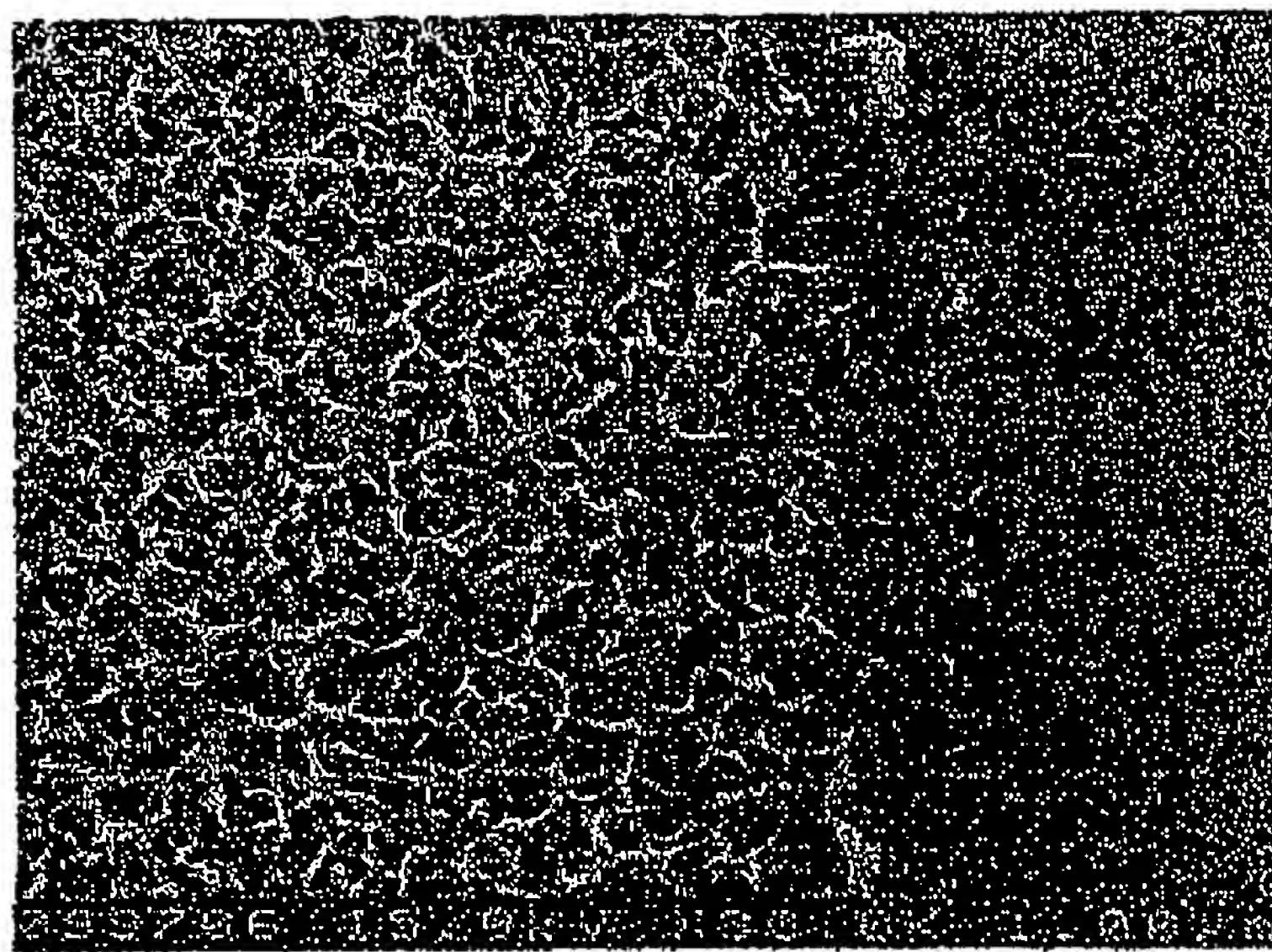


Fig. 15

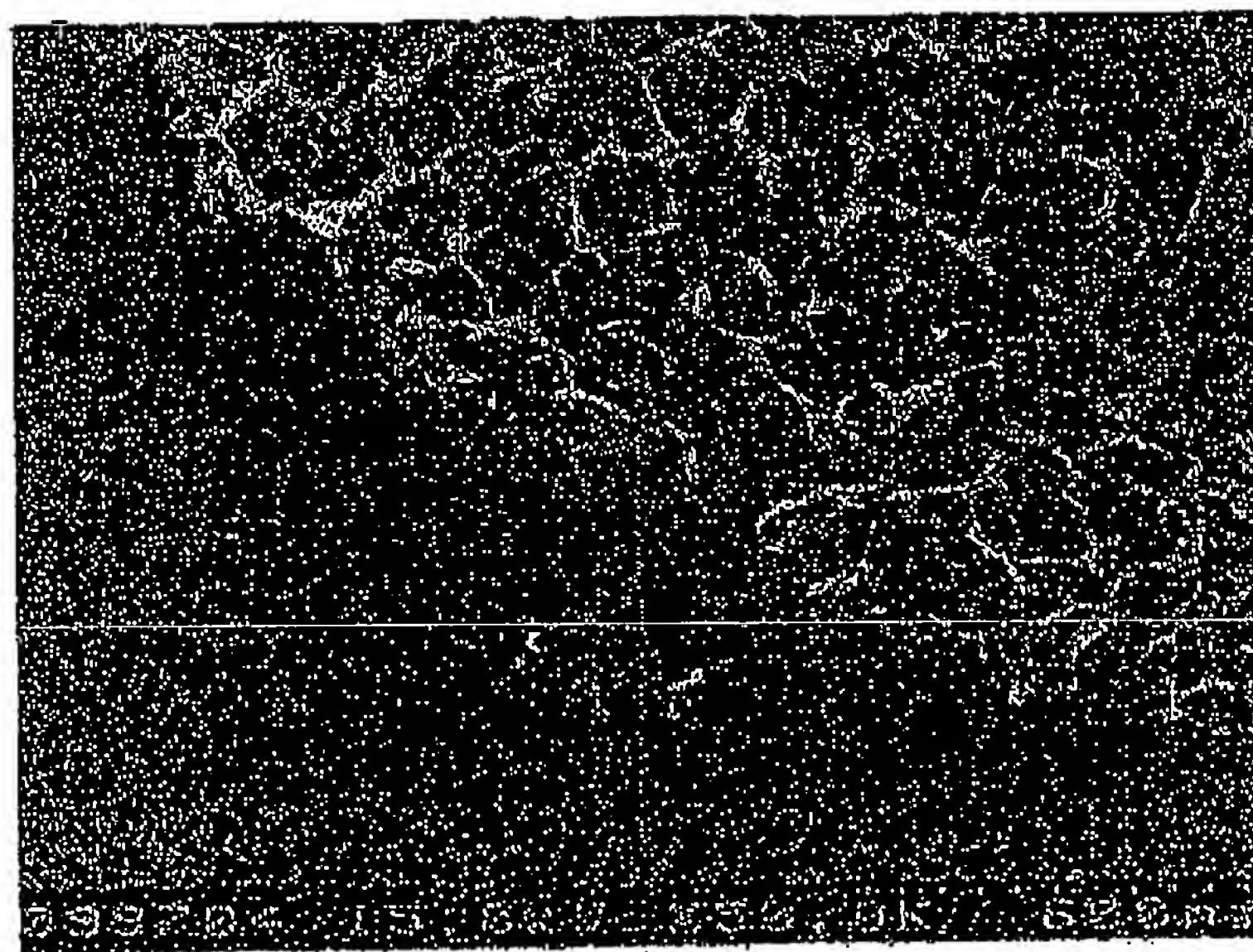


Fig. 16

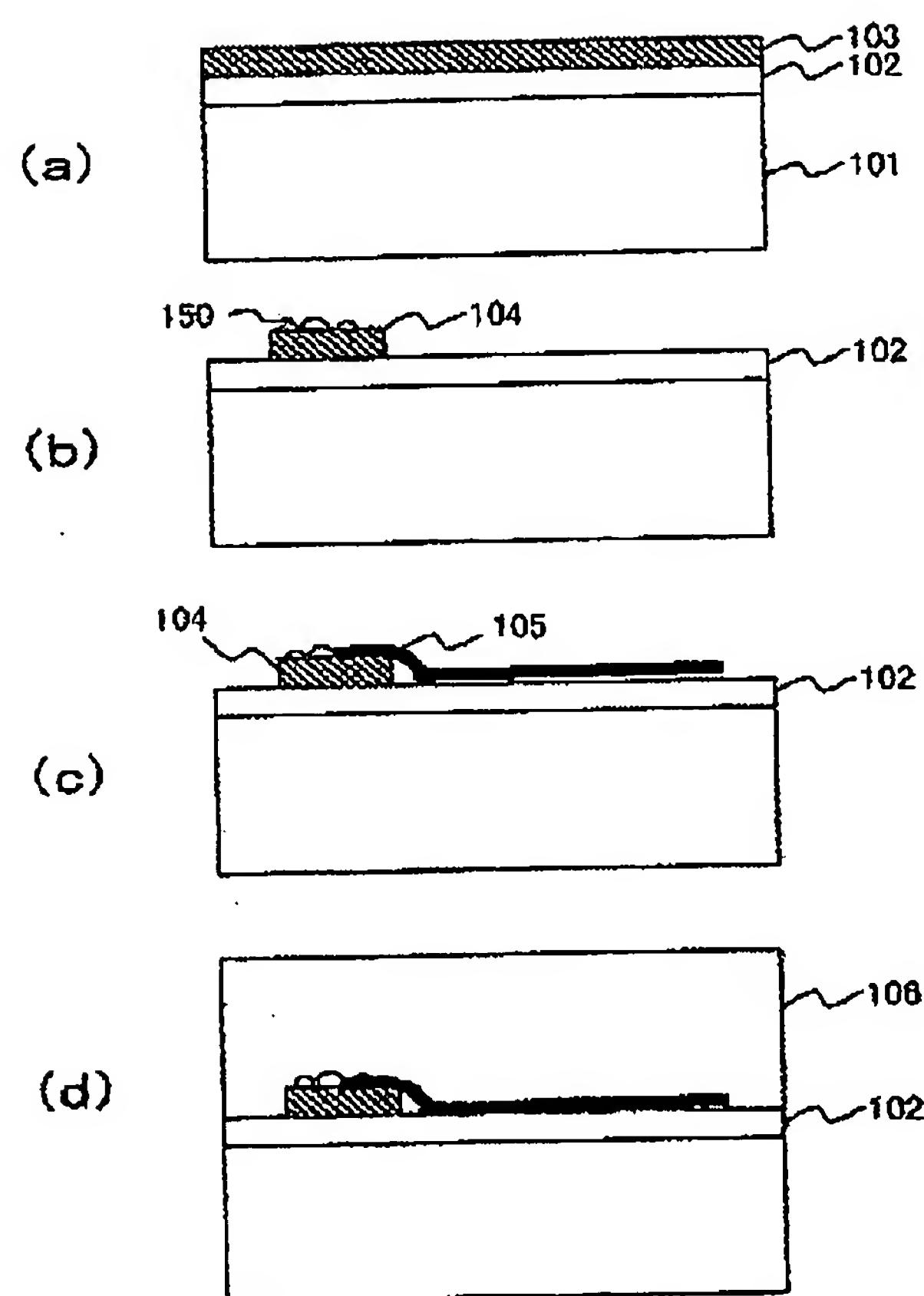


Fig. 17

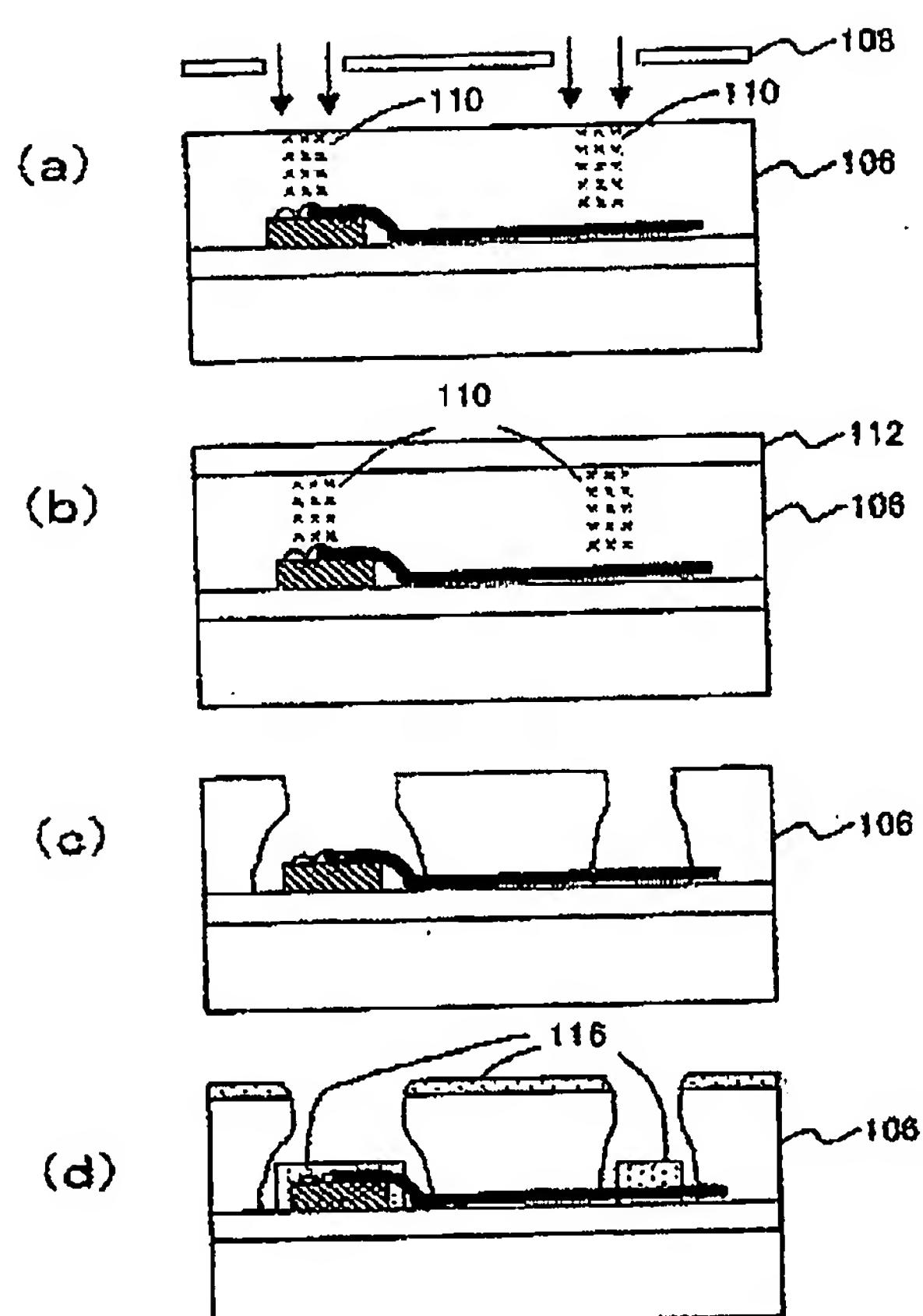


Fig. 18

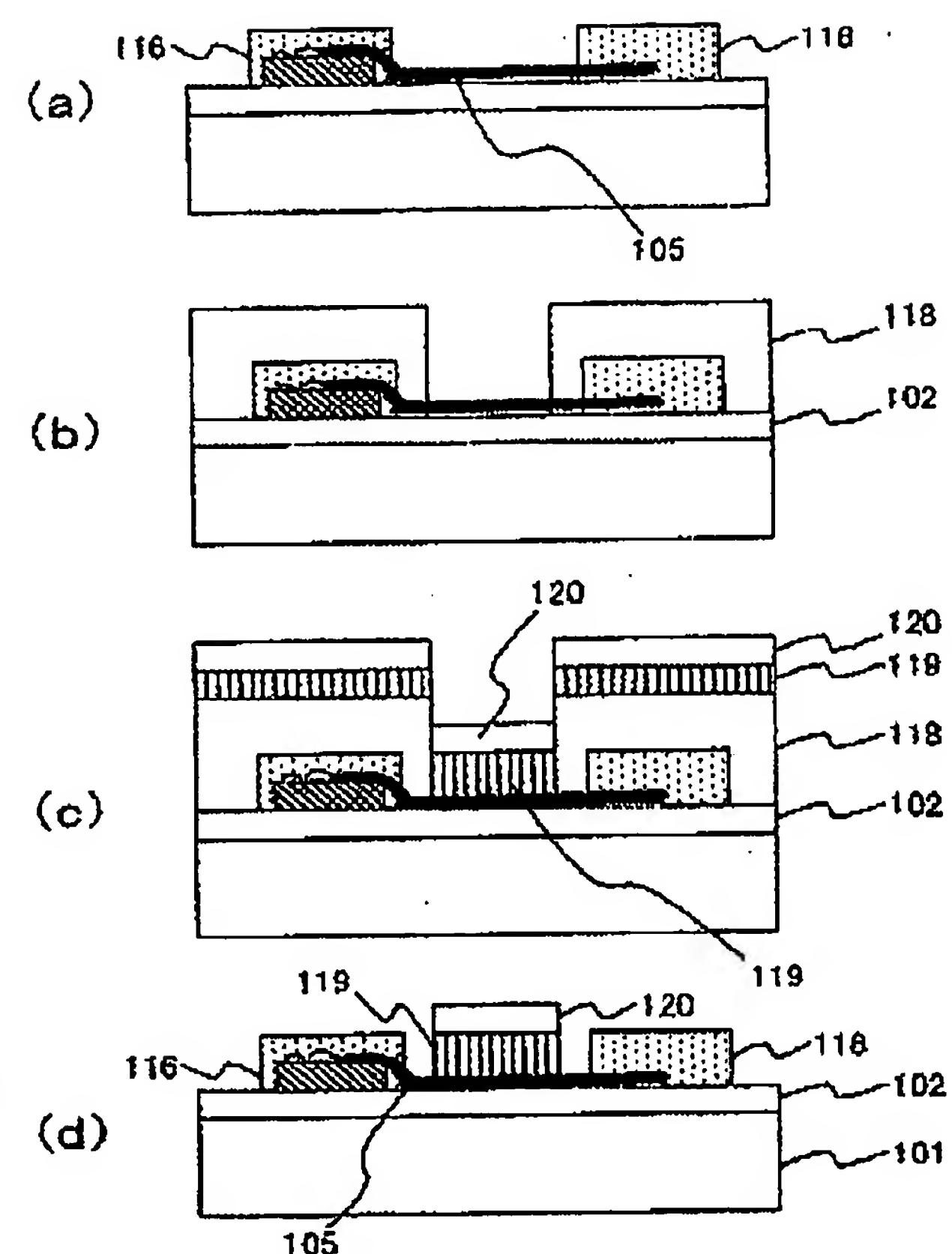


Fig. 19

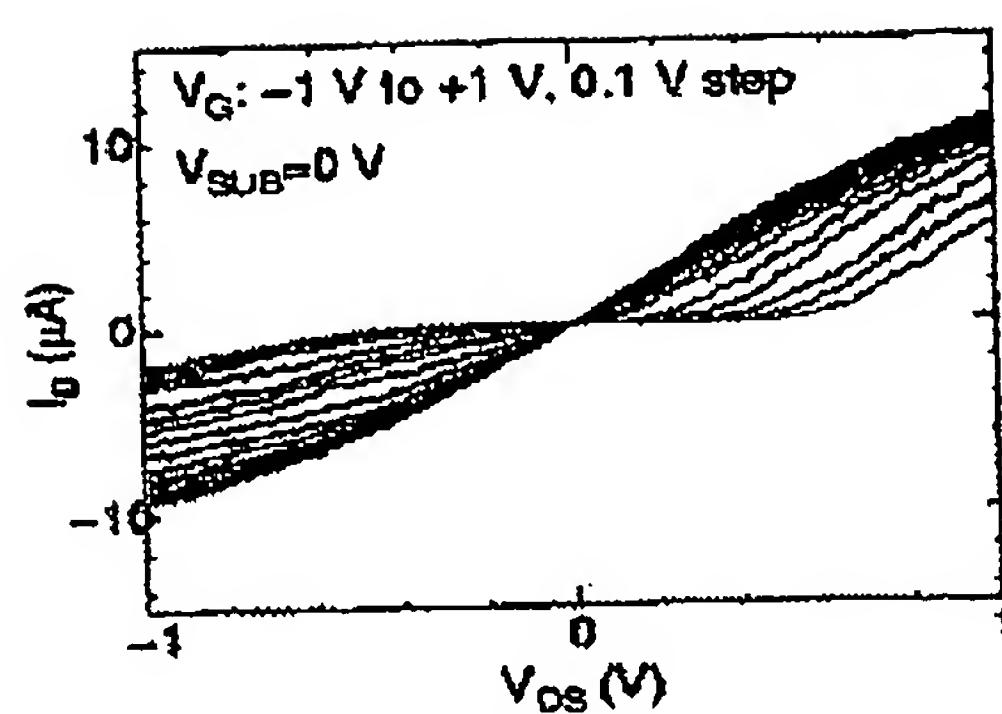


Fig. 20

2004-67413A

## Translation of JP 2004-67413 A

## [Title of the Invention]

CATALYST SUPPORT SUBSTRATE, GROWTH METHOD OF CARBON  
5 NANOTUBE USING THE SAME, AND TRANSISTOR USING CARBON  
NANOTUBE

## [Claim(s)]

## 10 [Claim 1]

A catalyst support substrate used for the vapor growth of a carbon nanotube characterized by comprising: a principal surface including

(a) a first field including a carbon nanotube vapor growth catalyst, and

15 (b) a second field including a metal containing at least one element selected from group 2 to 14 of periodic-table, or its compound (however, the matter chosen as the carbon nanotube vapor growth catalyst in the first field is excluded).

## [Claim 2]

20 The catalyst support substrate according to claim 1, characterized by that the carbon nanotube is a monolayer carbon nanotube.

## [Claim 3]

The catalyst support substrate according to claim 1 or 2, characterized by that the carbon nanotube vapor growth catalyst includes a 25 metal or compound containing at least one selected from group consisting of Fe, Ni, Co, Ru, Rh, Pd, Os, Ir, Pt, La, Y, Mo, and Mn.

## [Claim 4]

The catalyst support substrate according to one of claims 1 to 3, characterized by that the metal or compound constituting the second field 30 contains at least one element selecting from group consisting of Al, Mo, Ti, Ta, Cr, Cu, Mn, Mg, Zr, Hf, W, Ru, Rh, Zn, and Sn.

## [Claim 5]

The catalyst support substrate according to one of claims 1 to 4, characterized by that a catalyst support film containing the second field 35 and a catalyst film containing the first field and covering a part of the catalyst support film are formed in this order on the principal surface of the catalyst support substrate.

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